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A PRELIMINARY INVESTIGATION OF THE NUCLEAR VULNERABILITY OF TAC--ETC(U)
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A PRELIMINARY INVESTIGATION OF THE NUCLEAR VULNERABILITY OF TACTICAL AIR CREWS

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Rayford P. Patrick

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FOREWARD

The experiment described in this paper basically was designed and conducted to investigate a 10 hour strategic mission by a manned bomber, followed by a similar mission the following day (with no radiation exposure). Six subjects were trained, baselined, and completed the two ten-hour missions. The initial plan was to then euthanize the subjects and perform autoposies.

However, the amount of resources required to train and baseline the animals was quite high and I was not convinced that additional information could not be gleaned prior to the loss of such valuable subjects.

Study of the mission profile, task loading over the ten-hour mission, and radiation exposure profile led me to believe that the basic parameters of the experiment were also representative of the tactical sorties in response to a surprise nuclear attack. However even more valuable data could be gained if the past exposure runs were extended for several days to account for the "seven - day war" postulated by the press.

I believe that a separate report providing the details of the experiment, <u>all</u> of the results, and conclusions unique to the tactical situation is more valuable than simply an extension to the report of the strategic mission results.*

This engineering study is the result. The data presented herein replicates the exposure and post-exposure (first day) performance data as well as the emetic data of the USAFSAM report*, but the performance data for

* Patrick, R. P. et. al. "Nuclear Survivability/Vulnerability of Aircrews: An Experimental Approach", SAMTR-81-1, USAF School of Aerospace Medicine, Brooks AFB, Texas, January 1981.

for the remaining post exposure runs is unique. The discussion of the performance and my judgement of the operation significance of the performance deterioration are also original. They are strictly my own interpretation of the results and hence should not be taken as official Air Force, SAC, or USAFSAM positions.

ABSTRACT

Four rhesus monkeys were trained to perform tasks representative of VFR flight. After several hundred hours of training to insure proficiency, they were subjected to 1440 rads of radiation delivered over a ten-hour period simulating several tactical nuclear sorties. They then continued to reaccomplish the same 10 hour workload on alternating days for seven days post-exposure. The results suggest that the supralethal radiation dose can be a significant performance degrader in the short term (up to 1-2 hours post exposure). But, there is recovery and significant performance capability exists for at least seven days post exposure.

A PRELIMINARY INVESTIGATION OF THE NUCLEAR VULNERABILITY OF TACTICAL AIR CREWS

INTRODUCTION

Nuclear survivability is defined by Air Force System Command Supplement 1 to Air Force Regulation 80-38 as ----"The capability of the system required to accomplish the designated mission in the presence of nuclear environments created by direct enemy attack or from collateral effects of a nearby nuclear detonation." This same directive charges the Aerospace Medical Division (via the USAF School of Aerospace Medicine) with the responsibility----"to establish and maintain an aggressive program to provide support and guidance to AFSC field commands and laboratories on human operator performance and biomedical aspects of systems survivability and vulnerability----".

To satisfy this requirement, the USAF School of Aerospace Medicine has established advanced research programs investigating the effects of nuclear weapons effects of nuclear weapons effects upon system operator performance. A key component of these efforts is advanced experimental research utilizing infrahuman primate subjects performing under controlled conditions simulating actual combat situations.

To date, these experiments have concentrated upon strategic combat situations involving bombers engaged on lengthy missions or other strategic systems. [1-3]. The results reported herein represent a preliminary effort to extend the effort to tactical nuclear conflict. Such conflict would probably involve shorter, more intense sorties, more demands upon the air crew, and more varied nuclear threats. Since this effort is preliminary in

nature, the results presented should not be construed to be ultimate answers but rather a springboard to productive communication with potential users resulting in more definitive future efforts.

EXPERIMENTAL METHODOLUGY

Obtaining useable and timely results from an experimental modeling effort is strongly dependent upon many factors such as the modeling techniques used, the data collection and preprocessing approach, and the data analysis procedures. Because of the criticality of the above factors, they will be discussed in detail in this section along with supporting rational. This discussion should provide operational personnel and other interested users insight into the experimental modeling approach and provide them a basis for evaluating the applicability of the results to their specific situations.

Subjects: Four naive rhesus monkeys (Macaca mulatta) weighing between 3.6 and 4.8 kg were selected as subjects for this experiment. Rhesus monkeys are anatomically similar to humans, possess similar digital manipulative capabilities, are capable of being trained to accomplish relatively complex tasks, and are relatively easy to handle.

Apparatus: The primate equilibrium platform (PEP) was selected as the primary apparatus in this experiment, because subject control of the PEP is similar to pilot control of an aircraft. The response characteristics of the PEP to control stick movement are also similar to those of an aircraft, both being rate controls. The PEP consists of a gymballed platform perturbed from the horizontal by an input forcing function. The subject compensated for these perturbations by manipulating a control stick.

To achieve more similarity to pilot workload, a discrete task was added. This discrete task, the Multiple Alternative Reaction Task (MART), consisted of a yellow cue light, an audible cue (a 1000 Hz tone) and four red lights, arranged as shown in Figure 1. The illumination of the yellow light (which was accompanied by the audible tone) was a cue for the subject to touch the NESA glass face of the cue light thereby extinguishing the yellow cue light. This response was immediately followed by the random illumination of one of the four red cue lights, requiring a touch to extinguish.

A combination of correct responses to yellow and red cue lights constitute a trial. However, if the subject failed to respond to the yellow cue light, it automatically extinguished after a specific period of time (5 sec) and the subject was negatively reinforced. In such cases, no red cue illuminated and the trial was over. Such trials consisted of only one yellow cue light. Following a correct response to the yellow cue light a random red cue light illuminated and remained illuminated for a period of

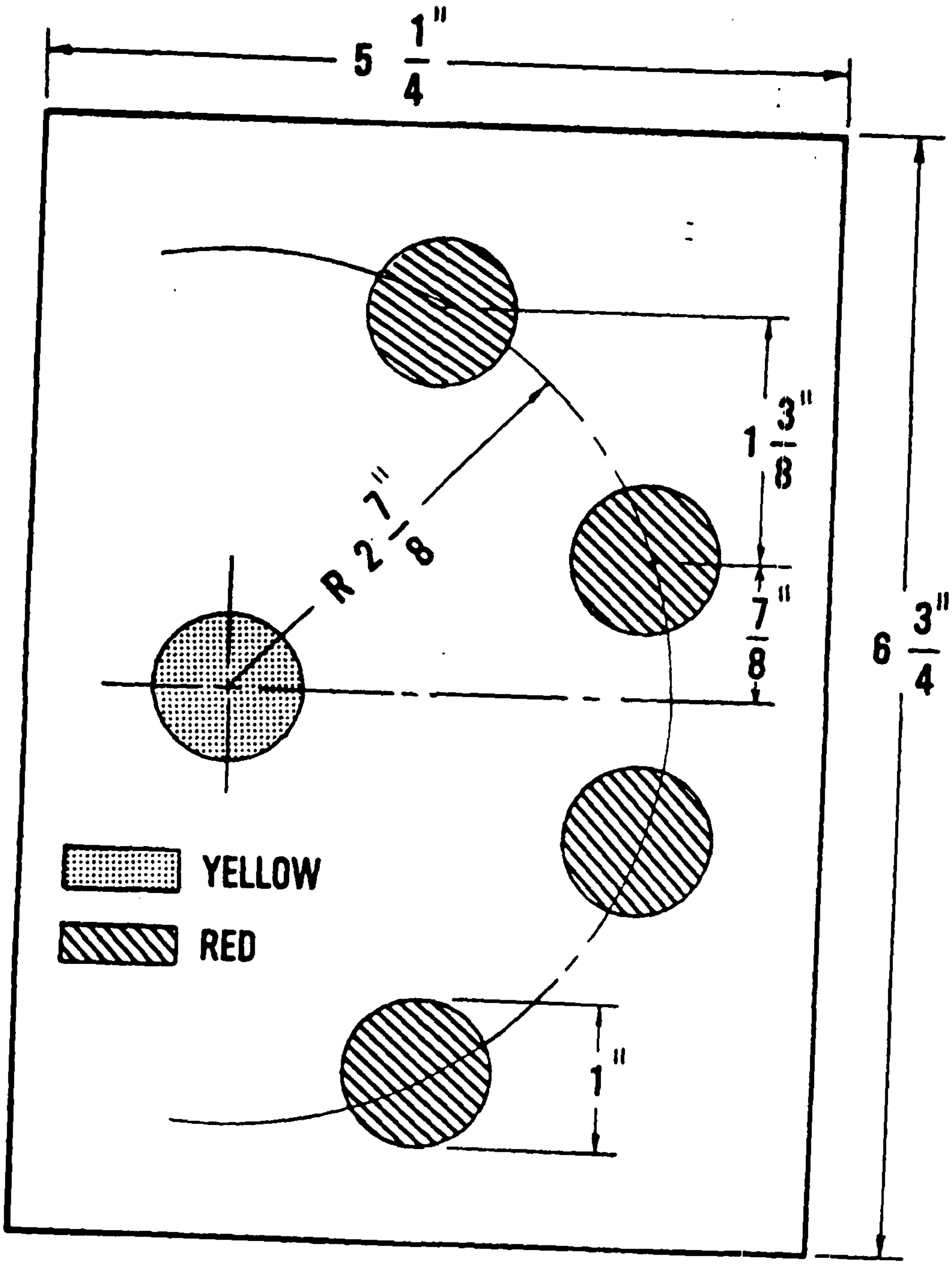

Figure 1. Front view of the Multiple Alternative Reaction Time (MART) apparatus.

time. An incorrect response, i.e. touching of an incorrect, or nonilluminated red NESA glass resulted in the extinguishing of the red cue light and concurrent negative reinforcement. Nonresponse to the red cue light after a specific time (4 sec) also resulted in the extinguishing of the cue and negative reinforcement. The MART was designed to closely approximate an aircraft master caution warning lgiht and engine fire lights. Such cockpit cues require discrete pilot responses similar to MART responses by the rhesus.

The combined task, PEP/MART is shown in Figure 2. Subjects were negatively reinforced via mild electrical shock applied through foot plates if: (1) the PEP was allowed to rotate more than 10 degrees from the horizontal, (2) the subject did not respond or (3) the subject responded incorrectly to the MART cue lights. Shock reinforcement provides higher levels of motivation to perform than does use of rewards such as food pellets. (This was evidenced in the work of Brown, et. al [1] where two groups of rhesus monkeys were trained to the same task using both techniques. Negatively reinforced subjects were much more stable in pre-exposure baselines and during radiation exposure than the food rewarded subjects.) Since aircrew motivation is assumed to be quite high during tactical missions, experimental subject motivation using negative reinforcement should be more realistic.

Simulation of Operational Parameters. To maximize the potential usefulness of the results of this experiment, the operational parameters of the tactical fighter engaged in combat was simulated. Although the basic concept of operations of such aircraft in a tactical nuclear conflict was not totally fixed, a typical day's activity in such a situation was hypothesized and this hypothetical day of combat was incorporated into the

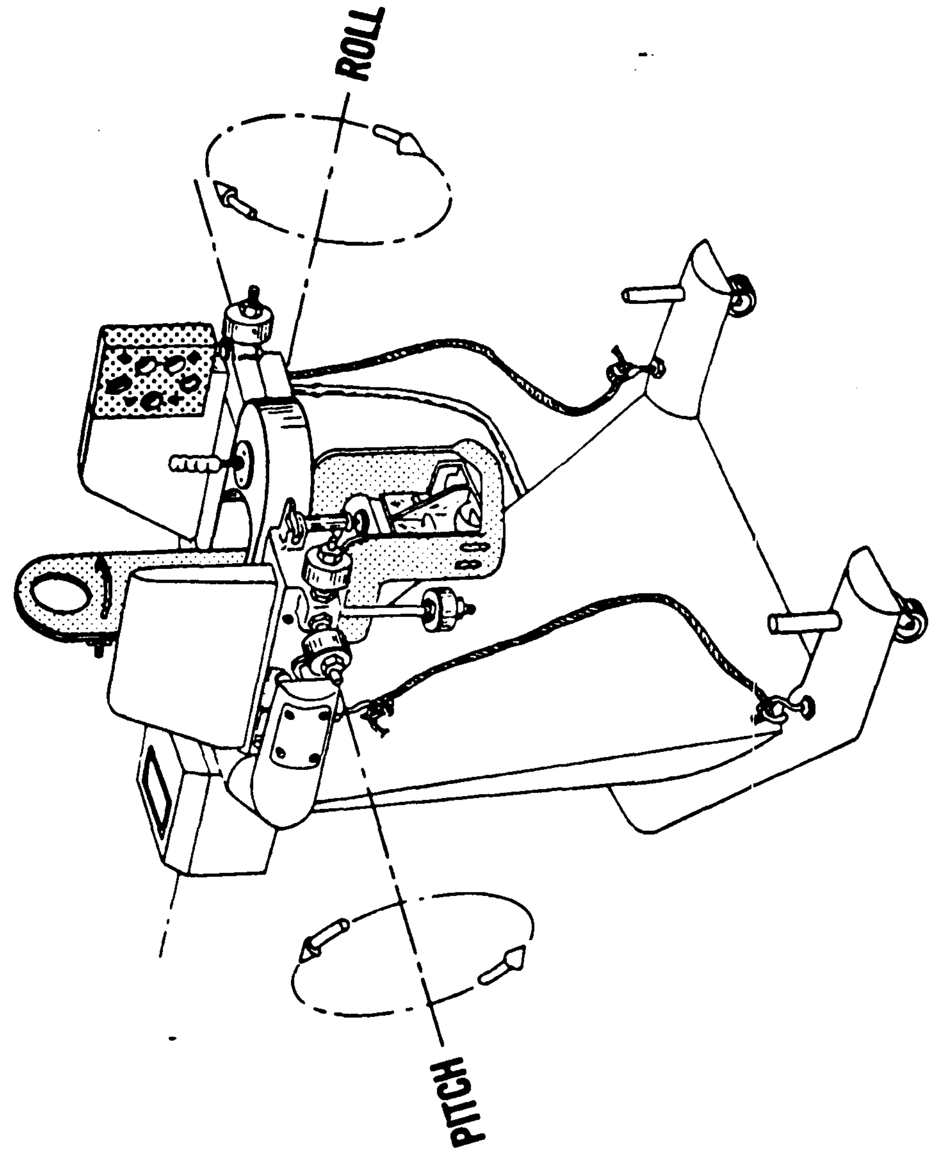

Figure 2. PEP/MART equipment

experiment. A total mission day of ten hours, consisting of four sorties was assumed. The first three sorties were one hour long, representing a typical fighter sortie length. The fourth sortie was 2 1/2 hours long and could be representative of a long range attack supported by one or more aerial refuelings. The lower line of Figure 3 depicts this assumed mission. Between each sortie, debriefing of the previous mission and planning for the next mission was accomplished.

After a basic combat day mission was selected we attempted to arrive at a reasonable radiation dose profile to be investigated. The doses selected were not the result of any detailed assessment of potential nuclear threats, but rather a hypothesis of the types of exposures tactical aircrews could experience. The first three doses shown on the second line of Figure 3 could be rather low-dose exposures an aircraft and crew in a shelter might experience resulting from hostile attacks on the base. The last and largest dose could be the result of exposure of an unprotected aircraft and crew at takeoff. It was assumed that the aircraft was unaffected by all the exposures.

The top line of figure 3 depicts the pilot workload and task as a function of the 10 hour day. During each sortie the PEP, which is analogous to pilot control of the aircraft, is the main task. The latter portions of each sortie however, includes the MART task as well. This increase in workload and task complexity should correlate with weapon delivery, defensive tactics, and other complicating factors occuring later in the mission. The MART task was continued between sorties to simulate debriefing and flight planning.

Since it is a popular notion in the press that a nuclear conflict in Europe would last only 7 to 10 days, we repeated the same schedule

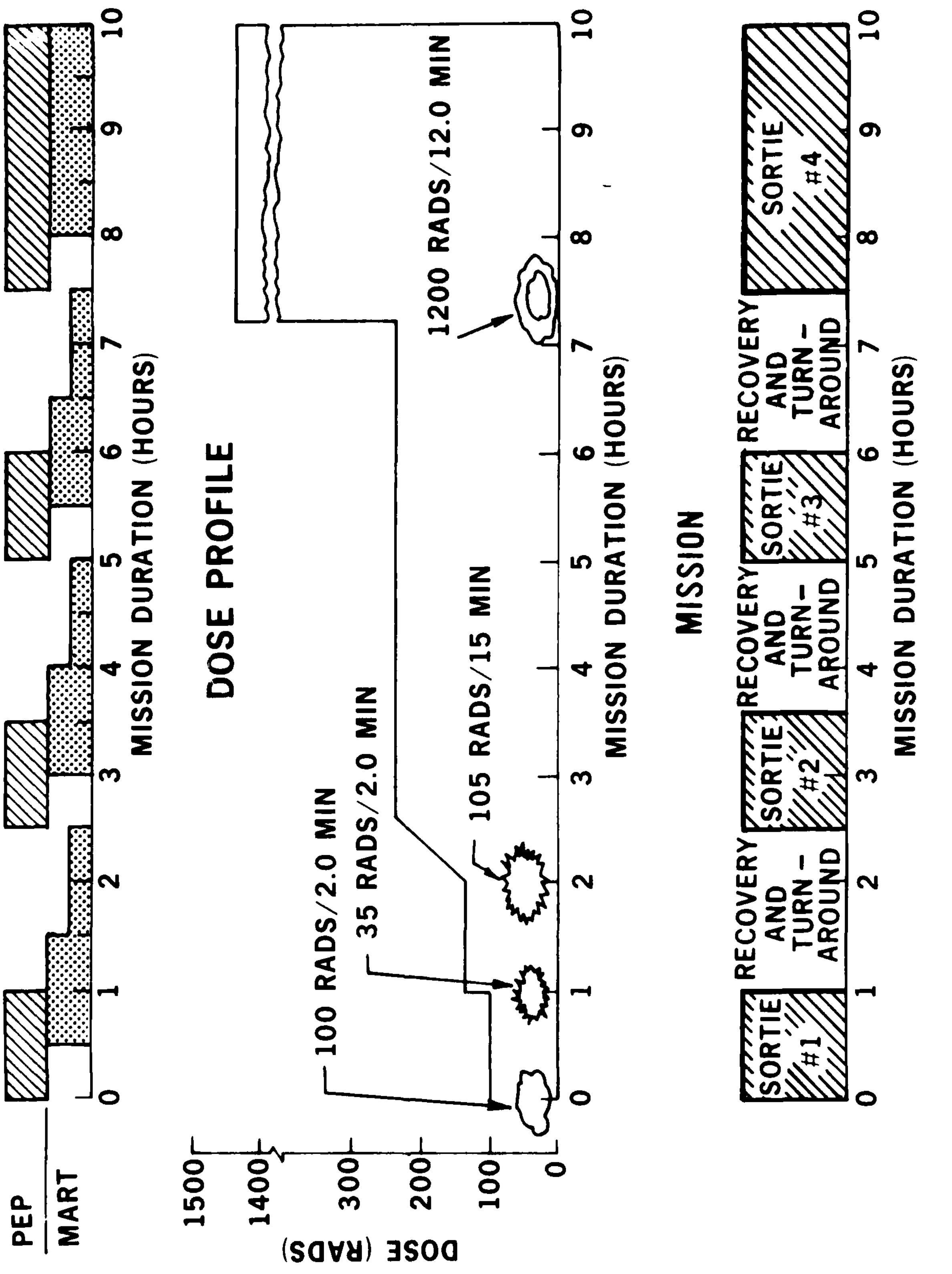

Figure 3. Crew Workload and Dose as a Function of Tactical Mission.

(excluding the radiation exposure) for 7 days after the supralethal exposure of the subjects to evaluate their performance capability. The subjects performed and data were gathered the first day, the third day, the fifth day and the seventh day post exposure.

The total crew dose accumulated over the ten hours was 1440 rads (incident tissue). This dose is supralethal to humans and would result in death over some period of time. However, effects of such a large but protracted dose on short term performance and during post-strike missions, may not be so drastic.

Procedure: The subjects were trained on PEP and MART using standard operant techniques. Initial training was conducted until the subjects met minimal task requirements. At this point, proficiency training was begun to allow the subjects to achieve performance stability as the subjects' workload was escalated to the identical parameters of the exposure run. Once the subjects' performance was reasonably stable, formal baselining procedures began.

During the baselining phase, data were taken and used to define normal, or pre-exposure performance. A total of seven, ten-hour baselines were conducted. Two PEP/MART's were used in this phase, but only one was used to establish the normal performance standard. Subjects in the alternate PEP/MART were essentially maintaining proficiency. The subjects were exercised every 3rd day (excluding weekends) in order to maintain stable performance over the duration of the experiment.

The establishment of stable performance was necessary for two reasons. First, pre-exposure performance definition required stable performance. Second, air-crew proficiency generally is high because of extensive simulator training, and normal proficiency training. Therefore realistic

simulation required similar levels of proficiency in the experimental subjects.

The exposure run was no different from the pre-exposure baselines except for the radiation exposure. The exposure run was followed by identical runs without radiation exposure to gain information about performance capability after initial exposure.

Because the standard baseline procedure involved several days of rest between runs, the past exposure data could have included an extra fatigue factor caused by lack of rest (only 12 hours instead of several days). Therefore baseline number 4 was started 24 hours after a previous run (either baseline 3 or a proficiency run) for each subject. The data from baseline 4 was analyzed to quantify any fatigue effects caused by inadequate rest which would then be considered in the analysis of the post exposure run to separate normal fatigue effects and radiation effects.

The ten-hour mission shown in Figure 3 was broken up into 20 half-hour sessions. Figure 4 depicts this arrangement. During each half-hour session the subject accomplished a specific set of tasks comparable with the pilot's activity for that session. The symbols P, M+ and M- refer to PEP control, MART operation at a high rate of 6 presentations per minute, and MART operation at a low rate of 3 presentations per minute, respectively. Between each session, a few minutes were allowed for setting up the new task, annotating the experimental log, and re-initialization of the computer which was collecting and preprocessing the data.

On the day of each baseline, exposure, and postexposure run, the subjects were fed at 0730, couched at 0815 and set to work at 0830. They

PEP/MART WORKLOAD

1	2	3	4	5	6	7	8	9	10		11	12	13	14	15	16	17	18	19	20
P	P M^+	M^+	M^-	M^-	P	P M^+	M^+	M^-	M^-	SNACK	P	P M^+	M^+	M^-	M^-	P	P M^+	P M^+	P M^+	P M^+

P = PEP

M^+ = MART (6 TRIALS/MIN)

M^- = MART (3 TRIALS/MIN)

Figure 4. Illustration of work requirements of subjects

performed continuously until completion of the 10th session at which time they were fed an orange* and allowed 15 minutes of rest. They then performed continuously until the end of session 20, when they were placed back in the cages, fed and watered.

*Performing animals generally refuse water. An orange however is readily accepted, provides moisture and nutrient, and simulates the consumption of a flight lunch by a pilot during the mission.

Performance Measures. The requirement to objectively define changes in performance caused by exposure to nuclear radiation (or any other stress) mandates the use of measures which accurately and reliably reflect subject performance. The continuous PEP control task was utilized in a prior effort (2). Those data indicated that the adjusted RMS, σ, of the instantaneous platform position, P (t), was the best measure of the subjects' average PEP control capability. This variable is defined as

$$\sigma^2 = \frac{1}{T}\int_0^T \left[P(t) - \mu \right]^2 dt$$

where μ is the mean platform position over the time period T.

$$\mu = \frac{1}{T}\int_0^T P(t)\, dt$$

Since the objective of the control task is to maintain a "horizontal" platform position by compensating for the input forcing function with the control stick, the instantaneous platform position is a key performance indicator. Taking the root mean square of this variable over some time yields a representative measure of the subjects' capability to perform the task during that time. Subtracting the mean platform position from the instantaneous platform position is necessary for animal subjects because they essentially control the PEP to avoid shock rather than to maintain a perfectly horizontal position.* That is to say, the experimenter cannot assume a monkey's concept of "horizontal".

*The shock limits were set at ten degrees from the horizontal which are relatively easy to avoid. (Most animals can maintain control within 3-5 degrees). This broad limit was deliberately selected to minimize the possibility of shock-induced artifacts in the data.

Thus, PEP performance is better reflected by the adjusted RMS, σ, which is measured with reference to the mean platform position over the time of interest, than by the RMS* which uses the horizontal as a reference. As an example, consider a subject maintaining near perfect control of the PEP, i.e., excellent compensation for the input, but whose mean platform position is 4 degrees. His RMS score would be about 5 degrees. Another subject barely capable of avoiding the ten degree shock limits, but whose mean platform position is zero, may also achieve a RMS score of about 5 degrees. Therefore, subjects whose performance capabilities differ drastically would still have similar RMS scores. Use of the adjusted RMS minimizes this concern. The first animal discussed above would have low adjusted RMS scores, while the seconds scores would be large, more accurately reflecting tracking skill.

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*The RMS of the instantaneous platform position, ψ, is

$$\psi^2 = \frac{1}{T} \int_0^T P(t)^2 \, dt .$$

The major measures of MART performance are times required to respond to yellow and red light cues and the accuracies of such responses. In addition to these objective measures, subjective observations of the subjects' performance capability and their observable reaction to the radiation exposure were made via a television monitor. The entire radiation exposure run was video taped for more detailed study. In these visual observations, behavior suggestive of nausea, fatigue, and discomfort, as well as the more obvious responses of retching and productive emesis were noted. Such observations provided additional insight into the subjects' general condition as well as their capability to perform the tasks satisfactorily.

DOSIMETRY. The first consideration in establishing dosimetry procedures was the determination of the dose profile to be utilized for the nonhuman primate subjects. The 1440 total dose discussed earlier was derived from an operational threat analysis and was presented in units of rads (tissue) incident upon the human crew member. This was essentially a free-field dose, i.e. the dose a sensor would register if placed on the surface of the crew members body. However, exposure of humans and monkeys to the same free field environment would result in different midline dose accumulations. The human is larger and the extra mass provides more inherent shielding. There are also differences between the radiosensitivity of humans and monkeys. These factors seriously compound the difficulty of laboratory simulation of the human operator in a radiation environment.

The optimum approach would be to apply established man-to-monkey radiation response criteria in the selection of the radiation dose to be administered. Were such intraspecies criteria available, the dose chosen for experimental purposes here would be based upon the dose-response parameters of the human and would become a simple mathematical extrapolation

for differing species. Such criteria are not available however, particularly for dose-response data based upon behavioral parameters. The only available information concerns the areas of lethality and radiation-induced emesis. The dose corresponding to lethality in 50 percent of exposed humans, the LD_{50}, is about 250-350 rads (midline tissue), while the dose required to evoke an emetic response the ED_{50} is about 180-200 rads (midline tissue) [4]. For Rhesus Monkeys, the LD_{50} dose is closer to 550-600 [5] rads while the ED_{50} for emesis is around 450 rads [6]. Based on these data, it would seem that the dose factor which should be used in order to equate radiation effects for the two species should be in the neighborhood of 1.5 to 2.0.

In this experiment, the monkeys were subjected to a total dose of 1440 rads (midline tissue). The midline dose of a human exposed to a free field dose of 1440 rads (tissue-incident) would be about 965 rads. The ratio 1440/965, or 1.5, corresponds closely to the above ratio based on comparative emetic and lethality data.

Prior to exposure, calculations of exposure configurations needed to achieve the required midline does and dose rates were performed and verified using instrumented phantoms. These phantoms were constructed of material with the same radiation response characteristics as the monkey. The exposure configurations are shown in figure 5. The animals were exposed anterior-to-posterior at distances from the source shown in the figure. Actual midline doses obtained were estimated to be with ±5% of the desired doses.

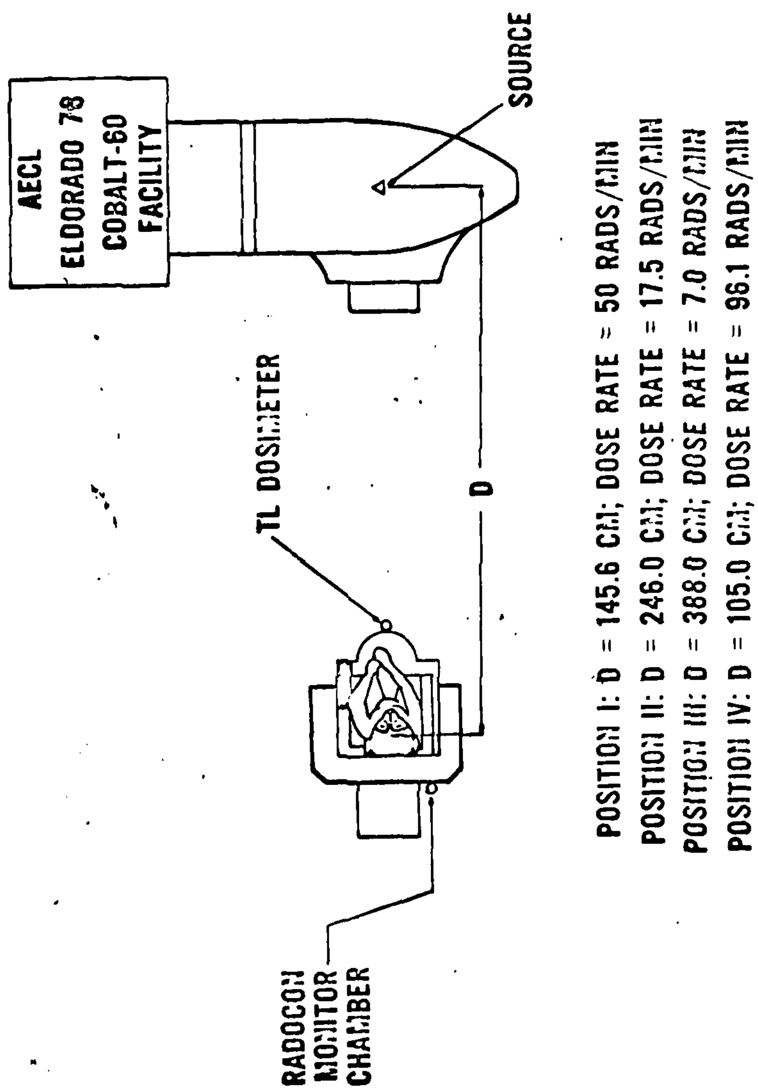


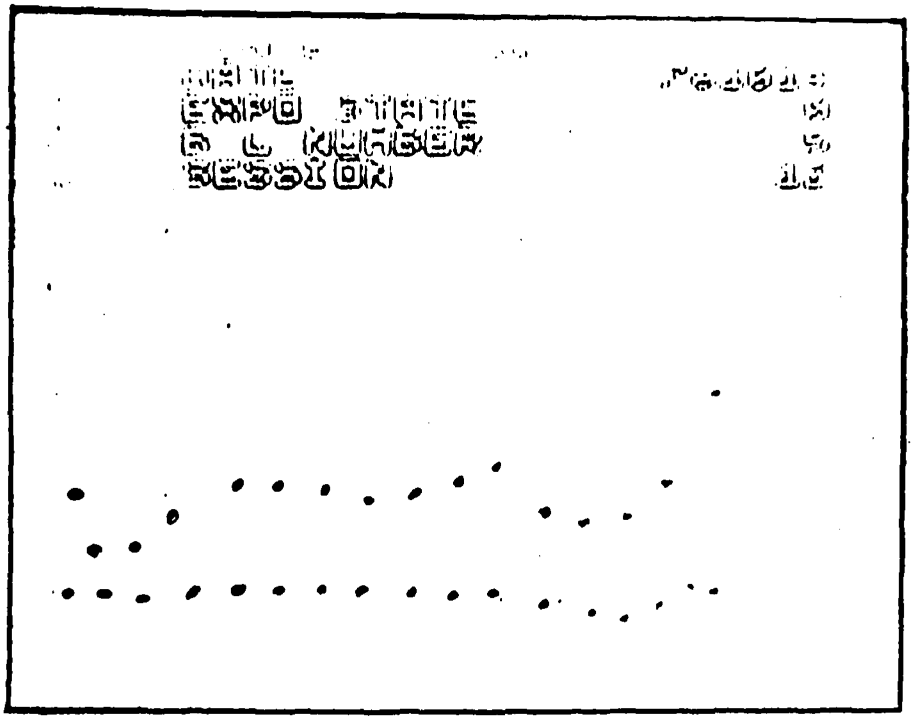
Figure 5. Exposure Configuration.

Data Collection/Preprocessing:

Attempts to realistically stimulate operational situations have required elaborate and complex data collection/preprocessing procedures and apparatus. For example, the utilization of multiple baselines to defines to define pre-exposure behavior resulted in a significant increase in the quantity of data taken. The use of longer periods, i.e. the ten-hour mission, and the development of more complex tasks, i.e. PEP-MART combined, also added enormously to the data required to adequately define pre and post-irradiation performance.

To cope with the increased data, we developed a data collection/preprocessing system based on a PDP-12 digital computer manufactured by Digital Equipment Corporation. The PDP-12 incorporates a real time clock, 8 channels of analog-to-digital conversion capability, 16K bytes of memory, and a teletype.

The instantaneous platform position signals were fed into the PDP-12 and the mean platform position and adjusted RMS of this signal were computed. Sense lines from the MART were also connected to the PDP-12 allowing calculations of response times and accuracies. For the above calculations, each 30-minute session was broken down into 15 two-minute epochs. The epoch scores were calculated, displayed on the CRT display, printed out on the teletype, and also recorded on magnetic tape for more detailed off-line analysis on the IBM 360. Samples of the on-line displays are shown in Figure 6. The on-line display was extremely valuable in monitoring animal performance, insuring that all parts of this experiment were functioning normally, and serving as a backup source of basic data in the event of a data loss or scramble in the IBM 360.



Output of CRT.

MONKEY NUMBER 54Ø
DATE 761Ø14
EXPO STATE Ø
B L NUMBER 5
SESSION 12

EP	APMS	PPO	#A	EA	#F	NR	IR	AVA	AVF	NS
1	1.514	1.736	12	0	12	Ø	1	1.Ø6	Ø.93	912
2	1.572	1.8Ø1	12	Ø	12	Ø	Ø	1.Ø8	Ø.97	893
3	Ø.999	2.3Ø4	12	Ø	12	Ø	Ø	1.19	Ø.96	1Ø75
4	2.Ø57	1.332	12	Ø	12	Ø	Ø	1.Ø3	1.Ø1	896
5	2.Ø66	1.622	12	Ø	12	Ø	Ø	1.Ø7	1.Ø2	884
6	2.Ø4Ø	1.269	12	Ø	12	Ø	Ø	1.17	Ø.99	875
7	1.911	Ø.961	12	Ø	12	Ø	Ø	1.19	1.Ø3	866
8	1.99Ø	Ø.149	12	Ø	12	Ø	Ø	1.13	Ø.99	872
9	2.Ø39	1.174	12	Ø	12	Ø	Ø	Ø.99	Ø.96	866
1Ø	2.273	Ø.694	12	Ø	12	Ø	Ø	1.17	Ø.95	[illegible]
11	1.756	Ø.597	12	Ø	12	Ø	Ø	1.Ø8	1.Ø6	[illegible]
12	1.693	Ø.1Ø1	12	Ø	12	Ø	Ø	1.1[illegible]	1.ØØ	867
13	1.733	Ø.451	12	Ø	12	Ø	Ø	1.17	Ø.9Ø	852
14	2.Ø64	Ø.2Ø6	12	Ø	12	Ø	Ø	1.4Ø	Ø.96	846
15	2.97Ø	-Ø.Ø67	12	Ø	12	Ø	Ø	1.12	Ø.95	878

TAKE THE PICTURE AND HIT RETURN :

Printer Output

Figure 6. Typical Online Outputs.

Data Analysis:

More detailed analysis was performed after the epoch-score data were input into the IBM 360. The first step was the calculation of the standard deviations of the 15 epoch scores for each session and the selection of the worst case epoch score in each session. The standard deviation reflects performance variability over a session, and the worst case scores could be indicative of a temporary loss of control.

The next step was the merging of the epoch scores for each of the basic performance variables into session scores. For all variables except the adjusted RMS, simple averaging was sufficient. However, the adjusted RMS was recomputed using a characteristic time of 30 minutes rather than 2 minutes. At this point, all of the basic variables were subjected to a baseline trend analysis using the technique described in reference 2. This analysis indicated whether stable performance had been achieved for the variable of interest prior to exposure. A negative, or downward trend in the performance scores for succeeding baselines generally suggested the presence of learning curve effects in the data. A positive, or upward trend in the data indicated a worsening performance with baseline.

In the absence of baseline trends, normal performance is simply the cumulative average of the performance measure for the seven baselines. However, the presence of trends in the baseline data makes the all-baseline average somewhat questionable as a normal performance standard. The performance of a subject improving with each baseline at the time of irradiation is probably better reflected by the last (most recent) baseline than by an average of all baselines. Normally the all-baseline performance standard is preferred because day-to-day variability of the subjects' performance is incorporated.

An obvious disadvantage in the use of only one baseline as a standard is that the subject could perform unusually well or exceptionally poorly on any given day, resulting in a biased performance standard. It can be readily seen, however, that performance changes indicated by comparative analysis using both standards, i.e. all-baseline and last-baseline, are highly credible.

The comparative analysis, then, consisted of comparing the subjects' performance during radiation exposure to normal performance using both the all-baselines standard and the last baseline standard. The range of performance with 95% confidence that 95% of the performance data were contained within the limits (95%, 95%) was computed using a simultaneous tolerance limit technique studied by Rahe (7). The normal performance standards were graphically portrayed as an average performance bounded by 95%, 95% tolerance limits. Exposure and post exposure performance scores were then graphed on the same coordinate system. Those exposure and post exposure scores falling outside the confidence limits were statistically significant (α=.05).

DISCUSSION OF RESULTS

The results obtained from this experimental investigation can be separated into two categories. The first is the numerical data indicative of performance capability in PEP and MART control. Recall that the performance metric of interest for the PEP was the adjusted RMS of the instantaneous platform position. For the MART, the response times and accuracies for the yellow (alert) light and the red (fire) light were the critical metrics. The second category of data consisted of visual observations of the subjects during exposure, and hence was more subject to personal bias then data compiled on the computer. However, this data is extremely valuable because subject discomfort, nausea, emesis and other radiation-induced symptoms are not easily amenable to automated data collection procedures and are not otherwise available.

<u>Quantitative Performance Data</u>: The first step in the analysis was the testing of the basic performance metrics for trends. The results of this test are shown in Table 1. Note that only one decreasing trend suggesting learning curve phenomena was detected. All of the other trends suggest worsening performance with baseline. Subject 566's decreasing trend was probably an experimental anamoly, as during the latter part of his last baseline the analog tape recorder providing the input forcing function apparently malfunctioned, providing a lower-amplitude forcing function. Therefore, this trend is probably due to an experimental discrepancy.

The worsening performance with baseline exhibited several of the animals may be an artifact of superbly trained subjects becoming familiar with the allowable operating limits and optimizing their strategy to achieve acceptable performance with minimal effort. Study of the data revealed that

TABLE I

Summary of Baseline Trends Analysis

	540	546	552	566
Adjusted RMS	NO	↑	NO	↓
Reaction Time, Alert Light	NO	NO	NO	↑
Accuracy Alert Light	NO	NO	NO	NO
Response Time Fire Light	NO	↑	↑	↑
Accuracy Fire Light	NO	NO	NO	NO

NO's indicate no trends ($\alpha = .05$).

↑ indicates improving performance with baseline ($\alpha = .05$)

↓ indicates worsening performance with baseline ($\alpha = .05$)

the absolute change in the scores of the subjects exhibiting trends was relatively small. All of the subjects had several hundred hours of operational time in the PEP/MART and were quite proficient. Therefore, even though some trends were present, they did not seriously confound the comparative analysis based on the all-baselines standard. Although the trend effects were generally small we conducted the comparative analysis based on the last-baseline performance standard to gain an extra measure of confidence in the results. Performance changes detectable in both approaches are highly credible because they are so significant they are not masked by the choice of standard.

Prior to continuing, recall that baseline 4 was designated a baseline fatigue run. The data from this run was treated as an exposure run and compared to the normal performance standards to determine whether back-to-back runs resulted in any detectable fatigue effects. This analysis revealed no significant effects. Apparently the overnight rest was sufficient for the subject to perform in a normal manner the following day.

Study of the results of Appendix A revealed many changes in performance during the exposure run and the four post exposure runs. Normal performance is indicated by the central line on all the figures. The upper and lower lines represent upper and lower 95%, 95% tolerance limits. The E's on the graphs symbolize performance scores during exposure runs, the O's performance scores during post exposure run. (1st day), the X's post exposure scores, (3rd day), the W's post exposure scores, (5th day) and the I's post exposure scores (7th day). All of the changes are summarized in Table 2.

From Table 2, it is noted that PEP cntrol capability, as reflected by adjusted RMS, was not impaired in subjects 540 and 552. But, subjects 546

TABLE 2.

Summary of Effects Detected.

		540		546		552		566	
		All Baselines	Last Baseline	All Baselines	Last Baseline	All Baselines	Last Baseline	All Baselines	Last Baseline
EXPOSURE	Adj. Rms	NO	NO	17,18, 19	17,18, 19	NO	NO	17,18	17,18
	Alert Time	7,8,17 19,20	17,19 20	17,18 19,20	17,18 19,20	NO	7,8,9,12 13,17,18 19,20	7,8,9, 10,14, 15,17, 18,19, 20	7,8,9, 14,15,17, 18,19,20
	Alert Acc.	17	17	17,18 19,20	14,17,18 19,20	NO	19	17,18 19,20	17,18 19,20
	Fire Time	17	17	NO	NC	7,9,12, 18,19,20	18,19, 20	7,8,9, 12,14, 15,17, 18,19	7,15, 17,18
	Fire Acc	NO	NO	17,19 20	17,19 20	6,18,19	NO	5,17, 19,20	5,17, 19,20
POST (1)	Adj. RMS	NO	NO	NO	NO	NO	NO	NO	NO
	Alert Time	3,8	NO	NO	NO	NO	7,17	3,4,5, 7	NO
	Alert Acc	NO	NO	NO	9	NO	NO	5,7	5,7
	Fire Time	NO	NO	NO	NO	NO	NO	14,15	NO
	Fire Acc	NO	NO	8	8	NO	NO	5	5
POST (2)	Adj. RMS	2,7	NO	6	6	NO	NO	6,11, 19	6,11 19
	Alert Time	NO	NO	7,12,17, 18,19,20	2,7,12,17 18,19,20	NO	7	4,7,8	NO
	Alert Acc	NO	NO	NO	17,19	NO	NO	NO	NO
	Fire Time	NO	NO	7,12,17 18,19	7,12 17,18	7	NO	NO	NO
	Fire Acc	NO	NO	18	18	NO	NO	NO	NO

TABLE 2 (con't)

		540		546		552		566	
		All Base-lines	Last Base-line	All Base-lines	Last Base-line	All Base-lines	Last Base-line	All Base-lines	Last Base-line
POST (3)	Adj. RMS	NO	NO	NO	NO	NO	NO	NO	NO
	Alert Time	NO	NO	NO	NO	NO	NO	NO	NO
	Alert Acc	NO	NO	NO	NO	NO	NO	NO	NO
	Fire Time	NO	NO	NO	NO	NO	NO	NO	NO
	Fire Acc	NO	NO	NO	NO	NO	NO	5	5
POST (4)	Adj. RMS	NO	NO	7	NO	NO	NO	2,7,18	2,7,18
	Alert Time	NO	NO	NO	NO	NO	13,14,15	10,13, 14,15	14,15
	Alert Acc	NO	NO	NO	NO	NO	NO	NO	NO
	Fire Time	NO	12	NO	NO	14	NO	5,10,13	10
	Fire Acc	NO	NO	NO	NO	NO	NO	5	5

NO's indicates no effect detected (α = .05)

Numerals indicates sessions where effects were detected (α = .05)

and 566 exhibited changes detectable in both comparative analysis techniques. However, MART performance did not fare as well with radiation. Effects were detected in every subject.

These observations suggest that the MART and PEP portions of the PEP/MART task demonstrated differential sensitivities to the radiation environment. If just the PEP control were the criterion for acceptable performance, the results presented above suggest that only one subject's performance during exposure was grossly degraded (subject 546), one subject's performance was marginal, (subject 566), and that the other two subjects' performance was only minimally affected. However, for the combined task, PEP and MART, two of the subjects exhibited grossly degraded performances (546 and 566), and two subjects' prformances were marginal during exposure.

Subjects 540 and 552 appeared to have recovered relatively well from the supralethel exposure and peformed the PEP/MART task with only minor difficulty up through seven days after exposure. Subject 546 also recovered and performed well the first day after exposure, had difficulty the third day and performed well during the 5th and 7th days. Subject 566 was the only subject who apparently experienced difficulty during the 1st day post exposure. He also had major problems the 3rd and 7th days, but performed well on the 5th day.

Visual Observations. As noted earlier, the subjects were closely observed during the baselines, exposure, and post exposure runs via closed-circuit television. In addition, the exposure and post exposure runs were video taped for more intense study. The objective of such scrutiny was to identify changes in behavior caused by the radiation exposure and to gain insight into the quantitative changes in performance detected in the comparative analyses discussed in the previous section.

Symptoms resulting from exposure to radiation include headache, nausea, emesis, malaise, marked weakness, anorexia, and in some cases temporary incapacitation or inability to maintain meaningful performance [8]. Since animal subjects cannot verbally communicate symptoms and because automated procedures to detect these kinds of effects are complex and unreliable, visual observations are required. The symptoms most conducive to reliable reports utilizing visual observation are productive emesis and incapacitation. In such cases, there is little doubt that the symptom exists. However, other symptoms are more subtle and the interpretation of visual observations more subjective.

Retching is rather difficult to quantify and its assumed precurser, nausea, is even more subjective in animal subjects. We defined retching as those movements which appeared to be involuntary contractions of the abdominal muscles, with or without open mouth (gagging) responses. Generally preceeding the retching responses were one or more spells of mouthing, or heavy chewing-like motions which are suggestive of nausea. Figure 7 depicts the retching and productive emesis observed during the exposure run. Note that two of the subjects experienced rather significant retching responses and mild productive emesis after exposure to the relatively low radiation doses delivered in the first two hours of the run. All four subjects experienced profuse productive emesis after the large dose administered at the start of session 16. No emesis or indications of nausea were observed after session 20 or during the next day.

All subjects displayed intermittent spells of listlessness and lethargy during the last five hours of the ten-hour experiment. This visual observation correlates well with observations made by others [8] for human patients and accident victims.

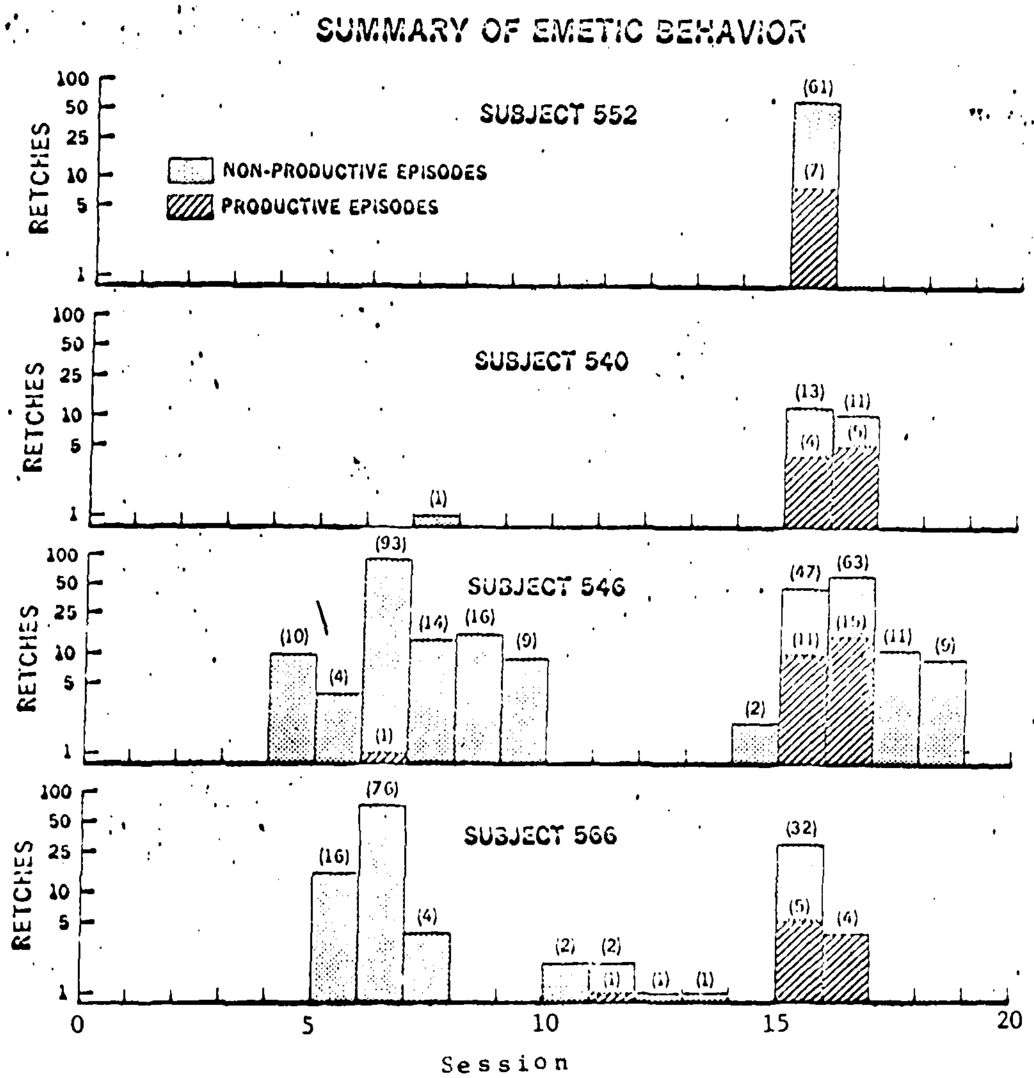


Figure 7. Summary of Emetic Behavior

Anorexia was also difficult to evaluate. The only early indication we had of anorexia during the exposure run was the refusal of two of the subjects to accept the fruit provided them after session 10. However, all of the subjects refused to eat their normal ration of biscuits at the completion of the 10-hour exposure run. In fact, except for minor exceptions, they all continued to refuse the biscuits during the remainder of the experiment. However they did accept and consume fruit, (i.e. apples and oranges) the day after exposure. This selectivity could be due to their preference for fruit or to the fact that the fruit contained moisture and was easier to consume.

Only two animals exhibited responses suggestive of incapacitation. Subject 546 completely lost control of the PEP in sessions 17, 18, and 19. His MART performance was also severely affected. Subject 566 was severely affected in session 17 and 18, maintaining only marginal control of the PEP, and almost totally ignoring the MART cue lights. During these periods, both subjects 546 and 566 appeared extremely lethargic and disoriented.

Visual observations tended to confirm the hypothesis that radiation effects were more radily observed in relation to MART, rather than PEP, performance. PEP control for the highly proficient animals seemed to be almost reflexive. Response to MART cues however required aperiodic concentrated effort and appeared to tax the subjects more heavily. In comparison, MART responses during baseline runs appeared casual and near reflexive to the observer. In general, performance decrement and emetic behavior appeared to occur at different times. The majority of the emetic episodes occurred 20-45 minutes after the start of session 16. The major performance changes were not observed until the very end of this emetic period (40 min) and lasted as long as 2 hours. During the emetic episodes,

the subjects appeared quite responsive and capable of relatively good performance although responses were somewhat more erratic due to symptom interference. Following this "emetic phase", the majority of the subjects exhibited an extreme degree of lethargy becoming almost catatonic in appearance. They slumped in their couches, performed erratically, and several exhibited exaggerated posturing.

Near the end of session 20, all subjects (even those most affected) had "recovered," in that performance was improved and the subjects appeared more alert to environmental cues. By the next day, all of the subjects were performing quite well with only relatively minor observable changes from their pre-exposure behavior.

Estimated Operational Significance. The results presented in the previous section demonstrated the performance of several of the subjects operating the PEP/MART to be seriously degraded for relatively lengthy periods. Because of the care and attention paid to the simulation of pilot duties and workload, these results should be useful in the estimation of radiation impact upon system survivability. It was assumed, of course, that no equipment or aircraft structure was affected by the nuclear radiation and associated nuclear environment. Only the aircrew members were considered.

It was assumed for the purpose of these estimates that the randomly selected subjects (Rhesus monkeys) respond to the 1440 rads (midline tissue) dose in a similar fashion as randomly selected pilots would respond to a 1440-rads (incident tissue) dose. This assumption is based on available data addressing monkey-to-man extrapolation.

The first step in estimating mission impact was the evaluation of PEP control capability (analogous to aircraft control via control stick manipulation), MART response (analogous to pilot response to discrete cues),

and emetic behavior which could be disruptive of performance during critical mission phases. Observer ratings reflecting estimates of the subjects' effectiveness were developed and utilized in an attempt to generalize from the laboratory to the operational environment.

For PEP control, a 0 rating was assigned when there was not detectable effect, i.e., performance was normal. A rating of 1 was assigned for minor performance decrement, a rating of 2 for major performance decrement, and a rating of 3 for catastrophic failure. A minor effect was defined as significant change in performance detected by only one comparative analysis technique or as a performance score only barely beyond the normal performance limits. A major decrement was recorded when the subject was only marginally in control of the PEP and the performance scores were well outside the limits of normal performance. A catastrophic failure rating was reserved for those cases where the PEP "crashed," i.e., rotated to an extreme angle and stayed there. In such cases, of course, there was no PEP performance as the subject was not responsive at all.

Somewhat similar criteria were selected for MART performance. A 0 rating defined normal performance and a rating of 1, minor performance changes. As a response time and accuracy measures were available as an evaluator of MART performance, these metrics were also used as a criterion of radiation effects on behavior. A statistically significant increase in response time or a decrease in response accuracy scores reflected only by one of the two comparative analysis was judged to reflect a minor performance change and assigned a rating of 1. MART performance changes were rated as major (2 rating) if response accuracies or response times were significant in both comparative analyses. Catastrophic changes (3 rating) were judged to be those where the response accuracies were less then 50%.

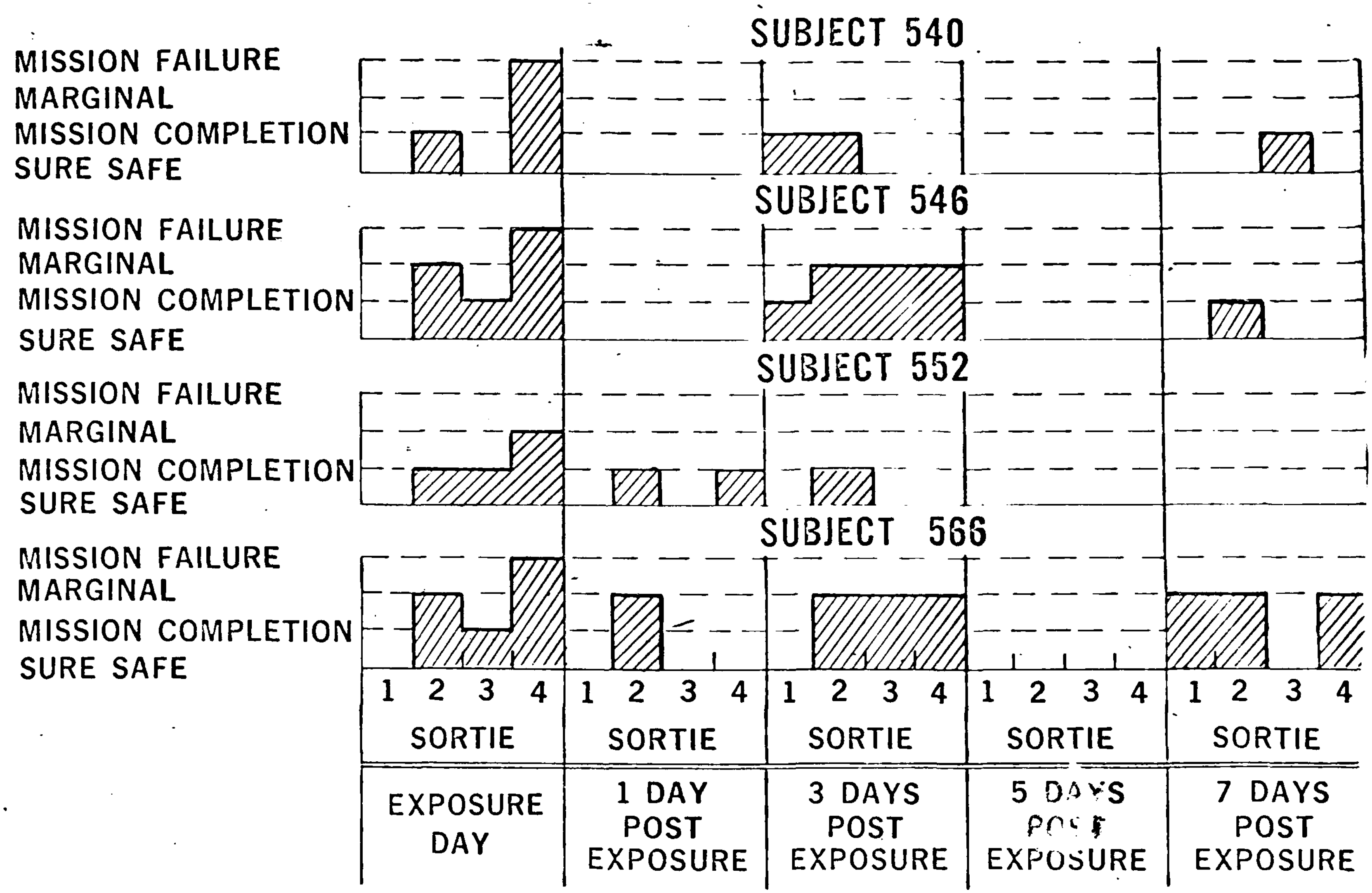
A rating system was also devised to estimate the operational effects of emesis. A rating of 0 was assigned to normal behavior and a rating of 1 to minor retching/emetic behavior (defined as 5 retches or less during a session). A rating of 2 (major effect) was assigned when a subject demonstrated numerous retching episodes, extreme nausea, and/or mild productive emesis. The 3 rating was reserved for those sessions where the animal exhibited severe retching and profuse vomiting.

Based on the results discussed previously, we finally estimated the overall capability of the pilot to maintain continuous control of the aircraft and readiness to respond to attack. A rating of 0 was assigned to the sure-safe estimates, a 1 predicted mission completion, and a rating of 3 predicted mission failure. A ranking of 2 was given to those situations defined by our criteria as marginal for mission completion.

Figure 8 summarizes the ratings for each subject on a graph which also displays the mission. Note that subjects 546 and 566 are judged marginal during the second sortie of the exposure day after having rceived only 240 rads. They were judged to be marginal performers primarily because of their emetic behavior. A pilot who is nauseated and is involuntarily retching in a pronounced manner may not be capable of accomplishing critical control tasks.

During sortie 4 of exposure day all subjects exhibited profuse vomiting and retching. Such behavior obviously interferred with critical psychomotor and, as such, its analysis has important operational significance. Later in this sortie subjects 546 and 566 became incapable of meaningful performance resulting in probable mission kill. Subject 540 was also affected to a major extent, probably resulting in mission kill for a fighter pilot.

Figure 8. ESTIMATED MISSION IMPACT



During the first day post exposure, three of four subjects were capable of mission completion for the same mission. The subject was judged to be marginal during sortie 2, but capable of completing the other three sorties. During the third day post exposure two subjects appeared to perform relatively well and two were marginal. All four subjects performed well the fifth day post exposure and three of four were performed adequately during the seventh day post exposure. Note that although there were several sorties during the post exposure runs where subject performances were judged to be marginal, there were no catestrophic lapses in capability, hence no probable mission kills.

CONCLUSIONS

The results of this experiment* suggest that free field radiation doses of 1400 to 1500 rads could seriously impact the mission completion capability of the tactical aircraft. A significant number of the aircrews could be rendered nearly incapable of meaningful performance for about 1-2 hours shortly after exposure (while the system itself may be minimally affected). While the remaining crews might not be incapacitated, they would be affected, some to major proportions, during the initial day of hostilities. However, the results also suggest that all of the crews, even those severely affected, recover from the exposure and regain capability for aperiodic meaningful performance, for up to seven days after exposure.

*The direct application of the results of this experiment to threat or survivability is not recommended because of the following reasons:

1. The PEP/MART is an improvement over previously used apparatus in the realistic portrayal of crew member tasks in the laboratory but still should be considered only a first order approximation. Basically it simulates pilot tasks during Visual Flight Rule (VFR) flight with limited discrete task loading.

2. The 1200 rad exposure at the start of sortie #4 should probably be prompt radiation consisting of a mix of high-energy neutrons and gamma radiation delivered in a few nanoseconds. The prompt dose was approximated in this experiment by an equivalent dose of 1200 rads of gamma radiation delivered over 12 minutes.

3. The interspecies extrapolation, i.e., monkey-to-man was addressed in this experiment only in terms of lethality and emetic behavior, the only presently available base for extrapolation.

4. The experiment utilized only four subjects, a rather small sample from which to estimate the statistics of large populations.

In light of the above, it appears that theater commanders may have more capability to resist tactical nuclear aggression than he might have anticipated.

REFERENCES

1. Brown, G. C., et al. Variables affecting radiation induced performance decrements. SAM-TR-77-3, USAF School of Aerospace Medicine, Brooks AFB, TX 78235, April 1977.

2. Barnes, D. J., et al. Protracted low-dose ionizing radiation effects upon primate performance. SAM-TR (in press).

3. Patrick, R. P., et al. An Experimental approach to the nuclear survivabilty/vulnerability of Strategic Air Crew. SAM-TR (in press).

4. Langham, W. H. (Ed.). Radiobiological factors in manned space flight. Pub 1487, Nat. Acad. of Sci., Natl Res Council, Wash, D.C., 1967.

5. Stanley, R. E., L. J. Seigneur, and T. A. Strike. The acute mortality response of monkeys (Macaca mulatta) to mixed gamma-neutron radiations and 250 KVP X-rays. AFRRI SP-66-23, Armed Forces Radiobiology Reasearch Institute, Bethesda MD, Dec 1966.

6. Personal communication with Lt Col Joel L. Mattsson, USAF School of Aerospace Medicine, Brooks AFB TX.

7. Rahe, A. J. On two-sided confidence and tolerance limits for normal distributions. M.S. Dissertation, Virginia Polytechnic Institute, June 1967.

8. Zellmer, R. W. Human ability to perform after acute sublethal radiation. Mil. Med. 126:681-687, 1961.

APPENDIX A

GRAPHICAL RESULTS

LEGEND

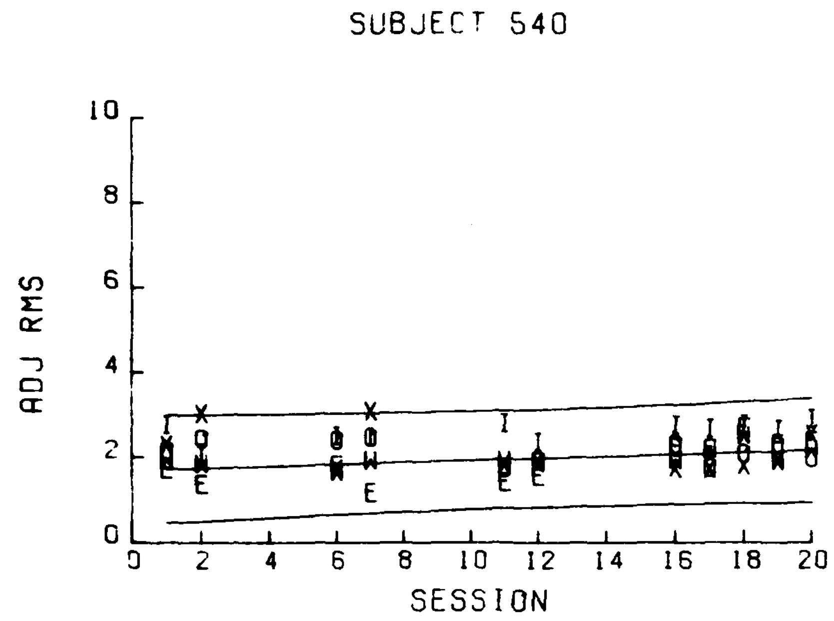
E - Exposure

O - 1st Day Post Exposure

X - 3rd Day Post Exposure

W - 5th Day Post Exposure

I - 7th Day Post Exposure



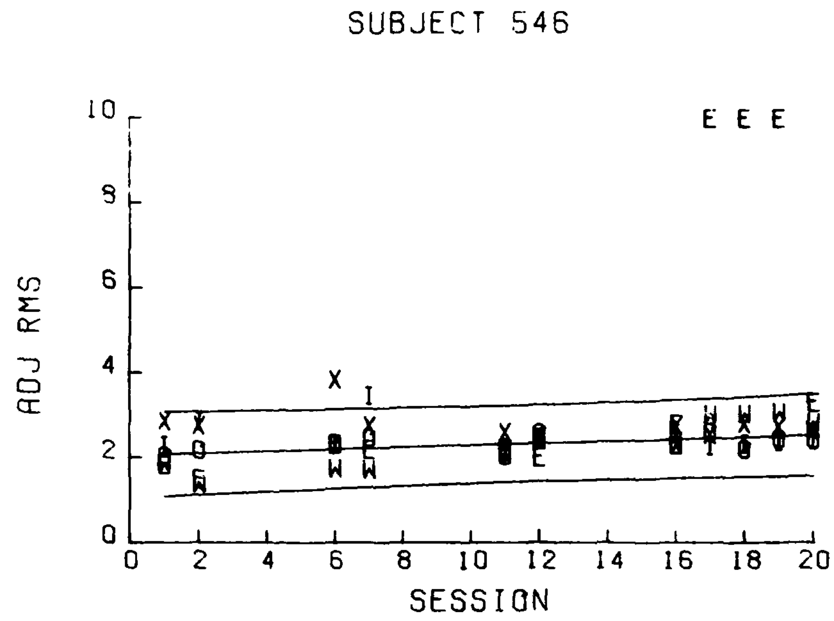
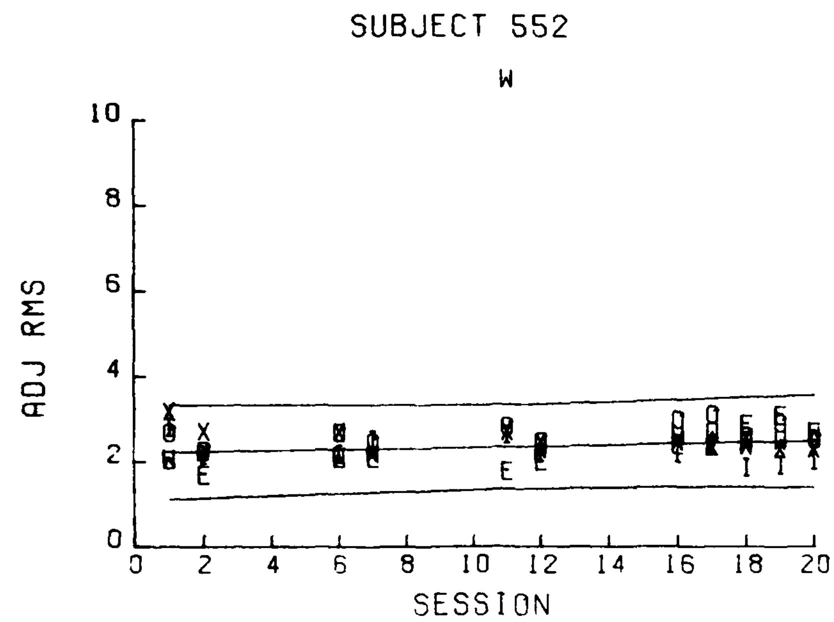
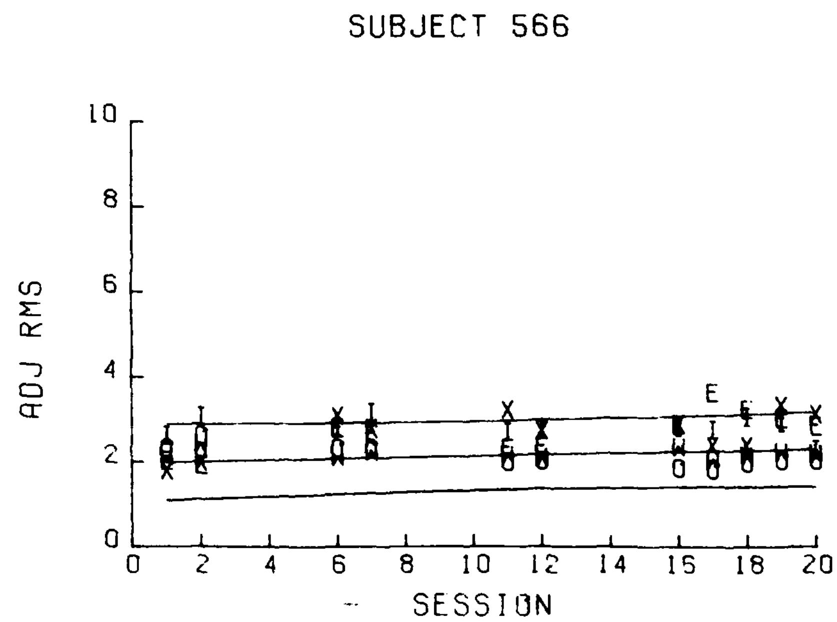
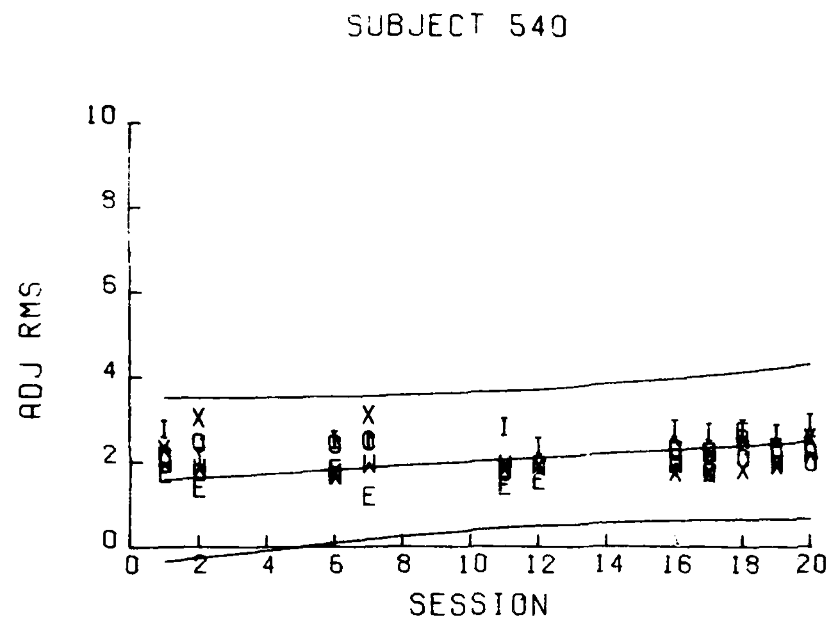


Figure A-1. Adjusted RMS - All Baselines Comparison







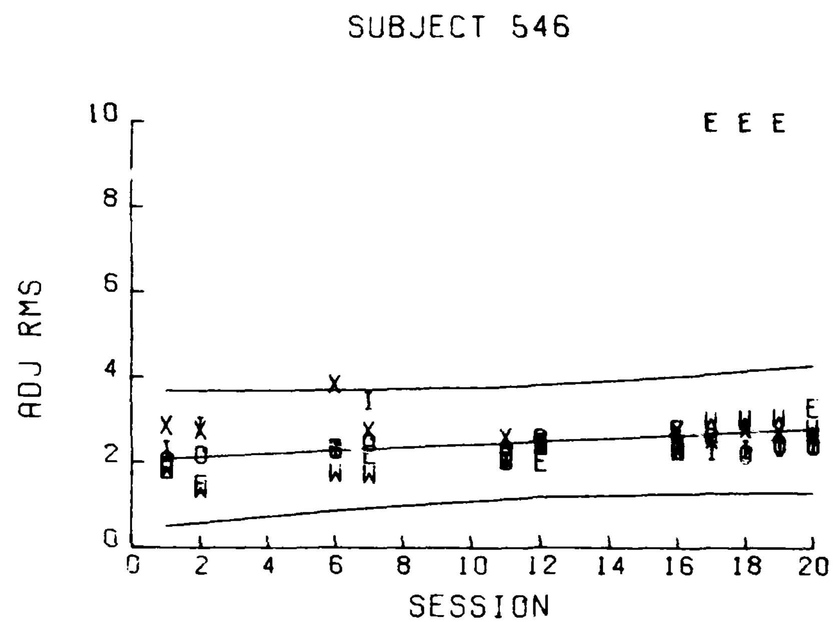
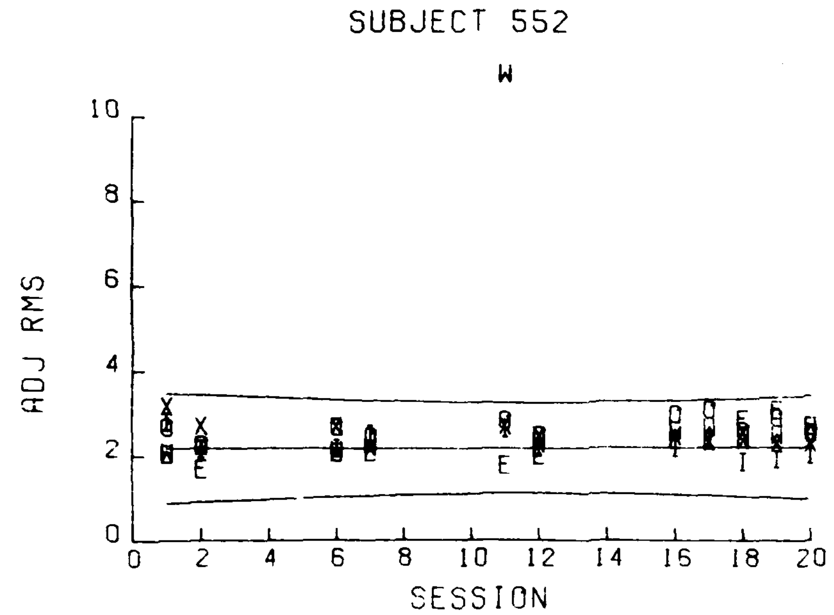
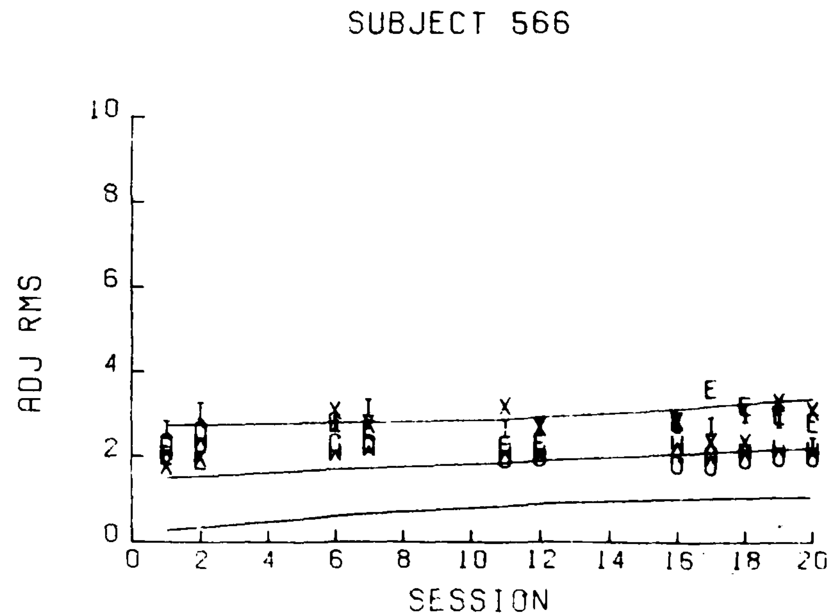


Figure A-2. Adjusted RMS - Last Baseline Comparison





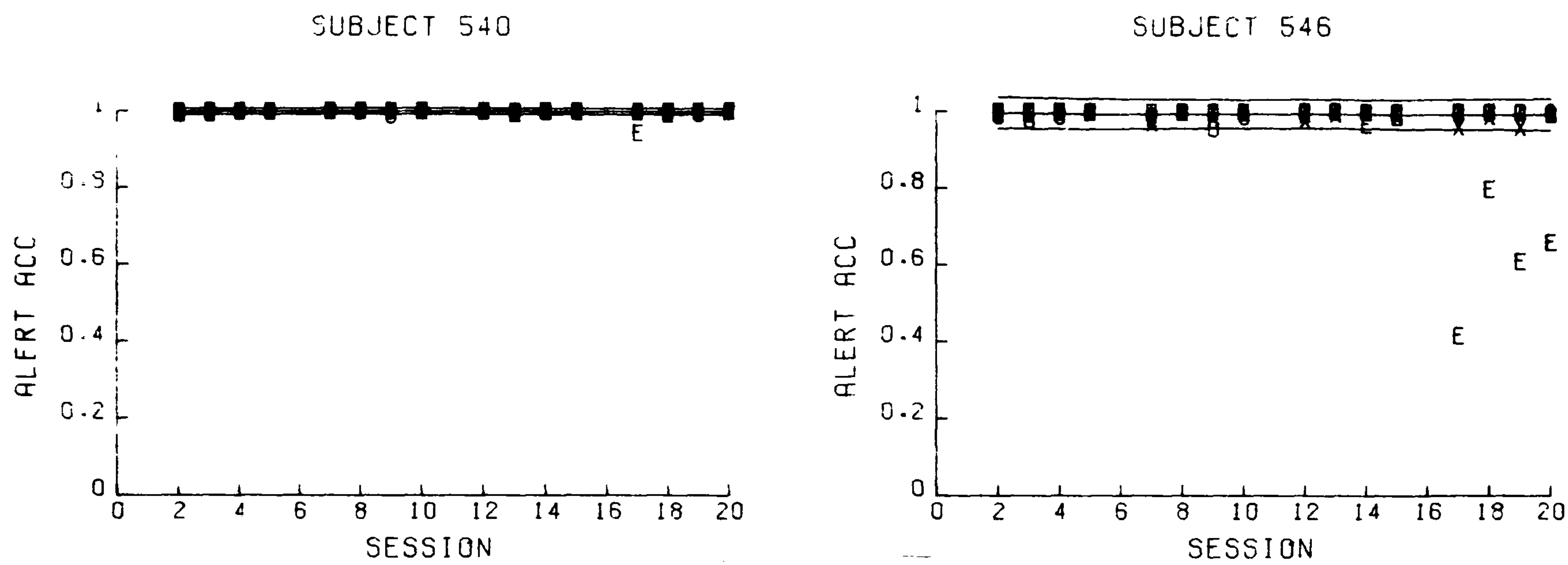
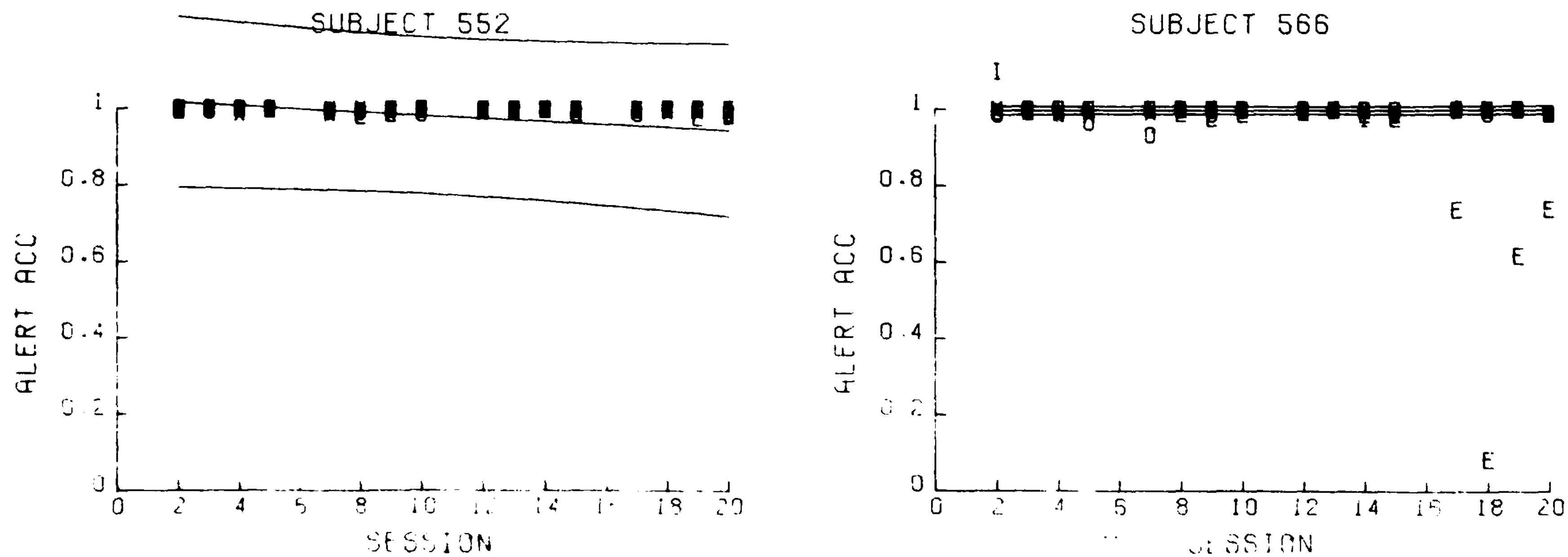


Figure A-3. Alert Light Accuracy - All Baselines Comparison



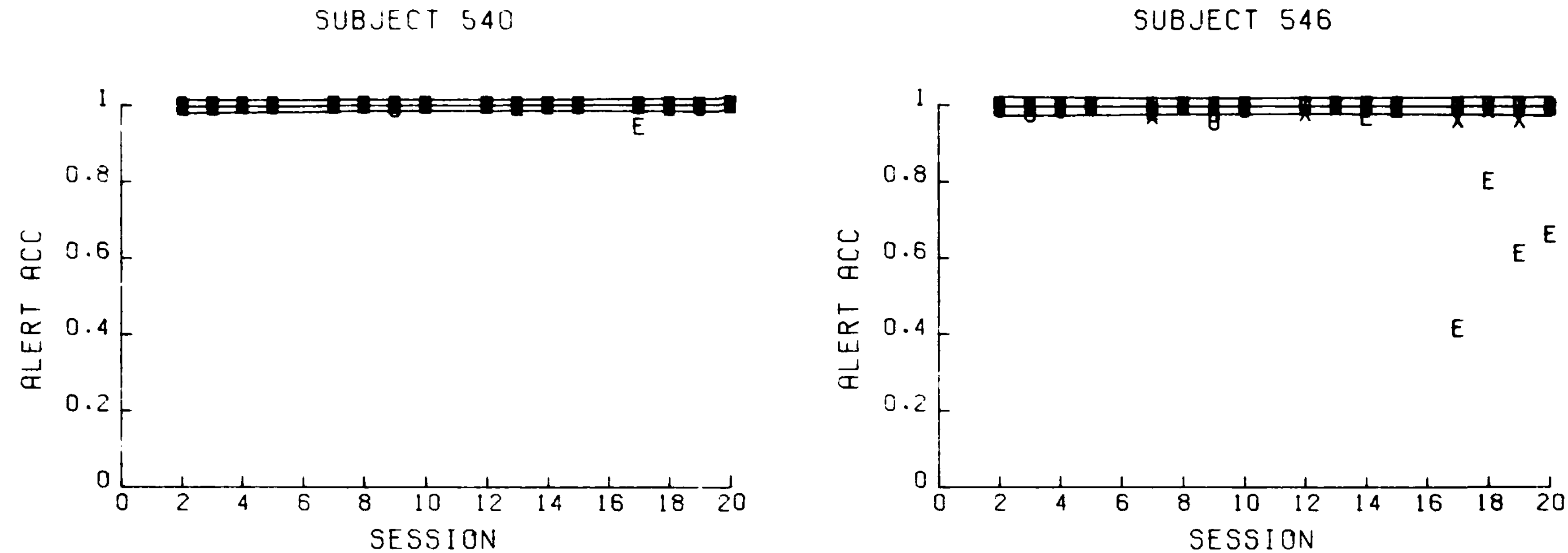
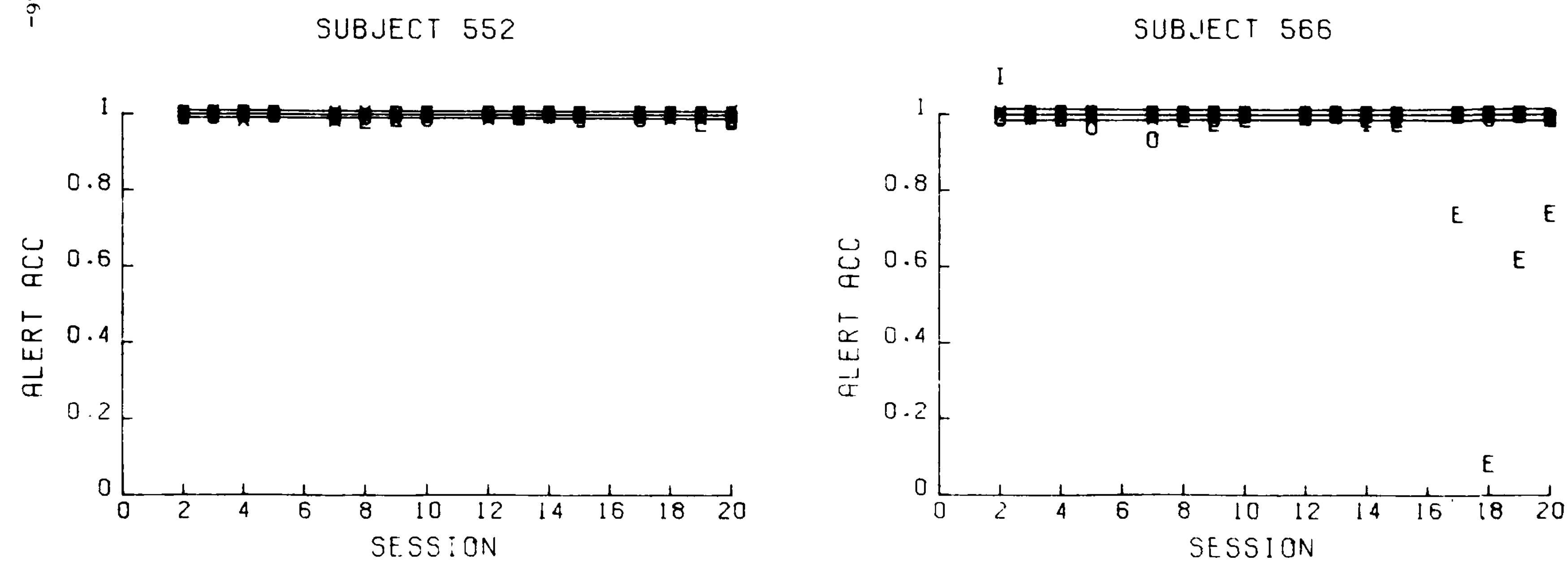


Figure A-4. **Alert Light Accuracy - Last Baseline Comparison**



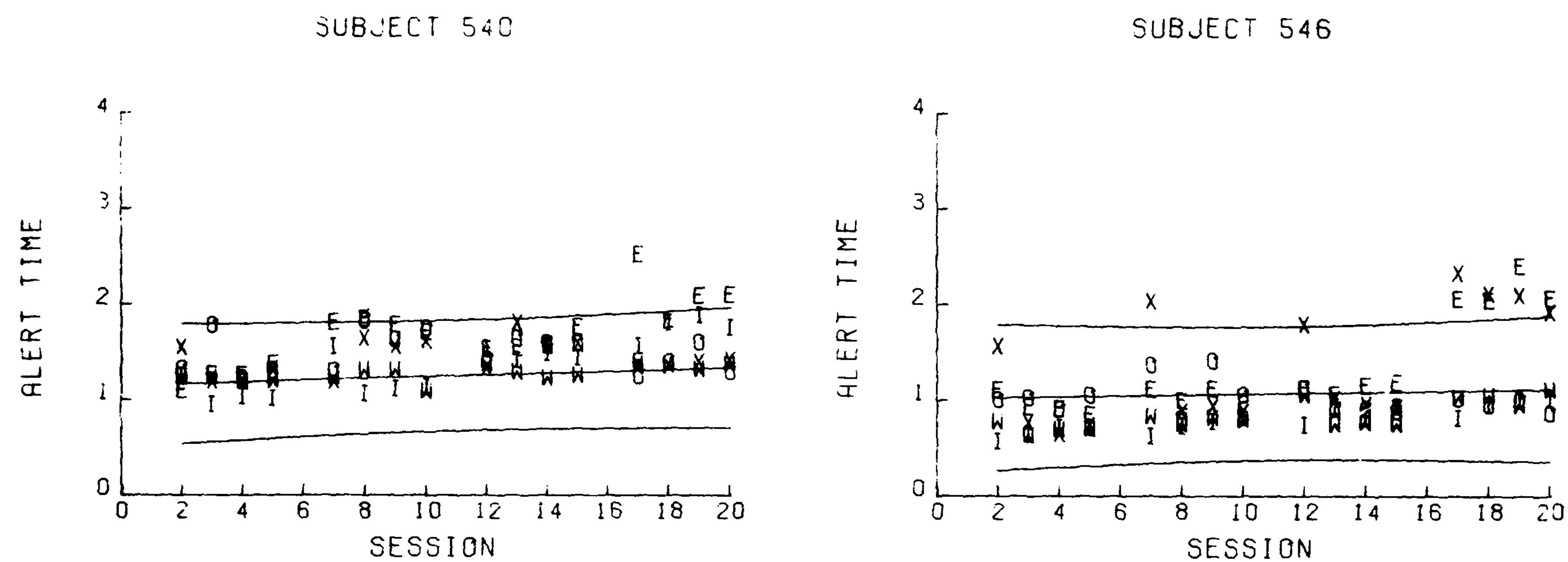
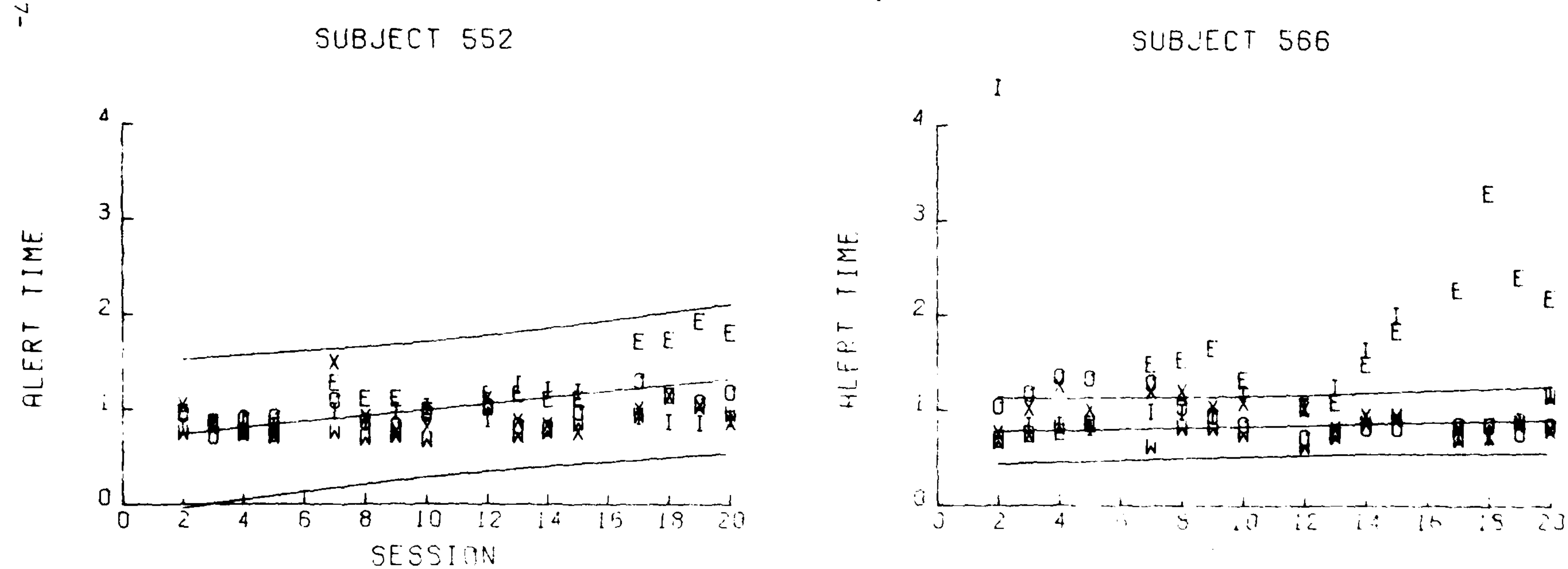
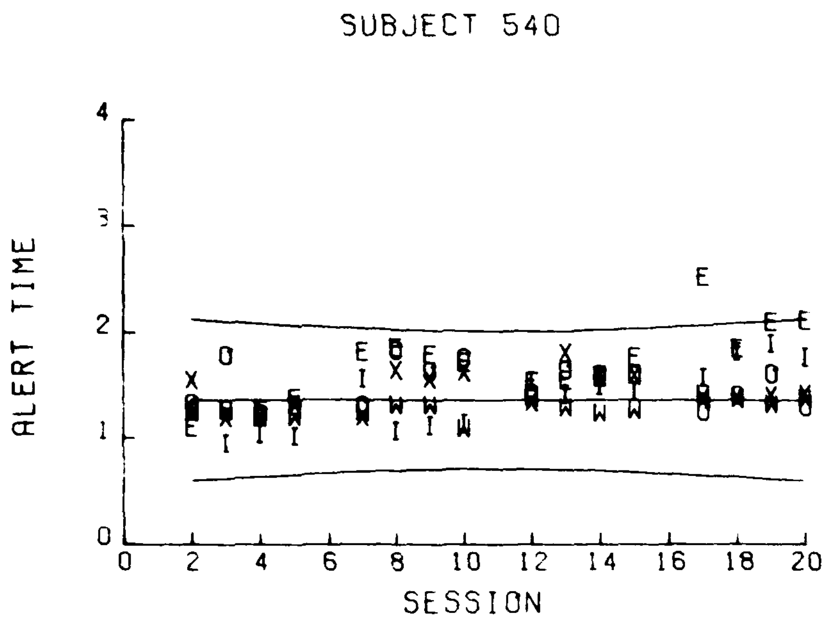


Figure A-5. Alert Light Reaction Time
All Baselines Comparison





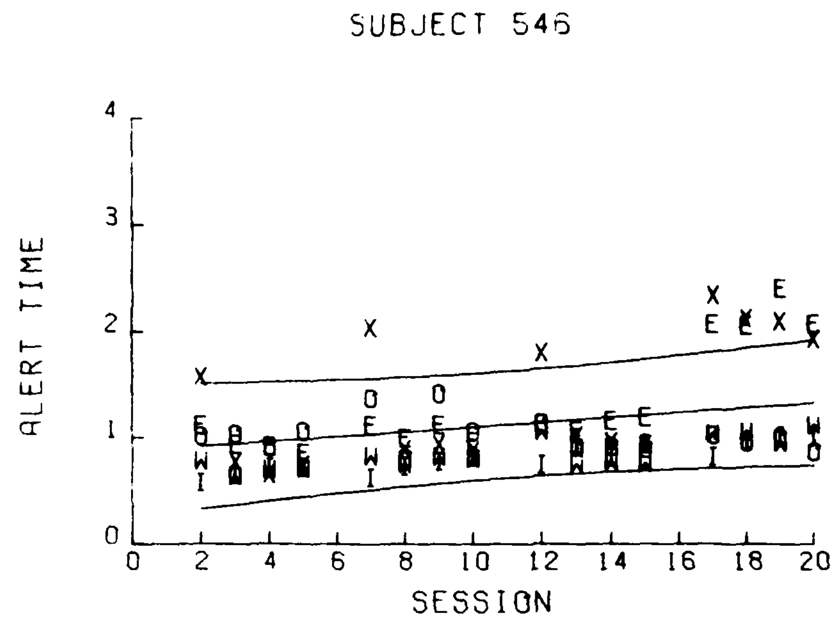
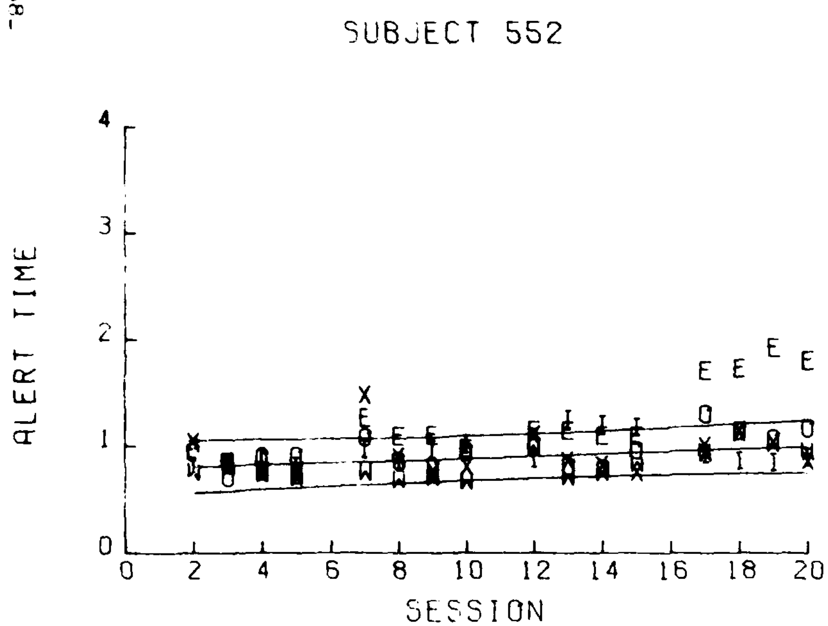
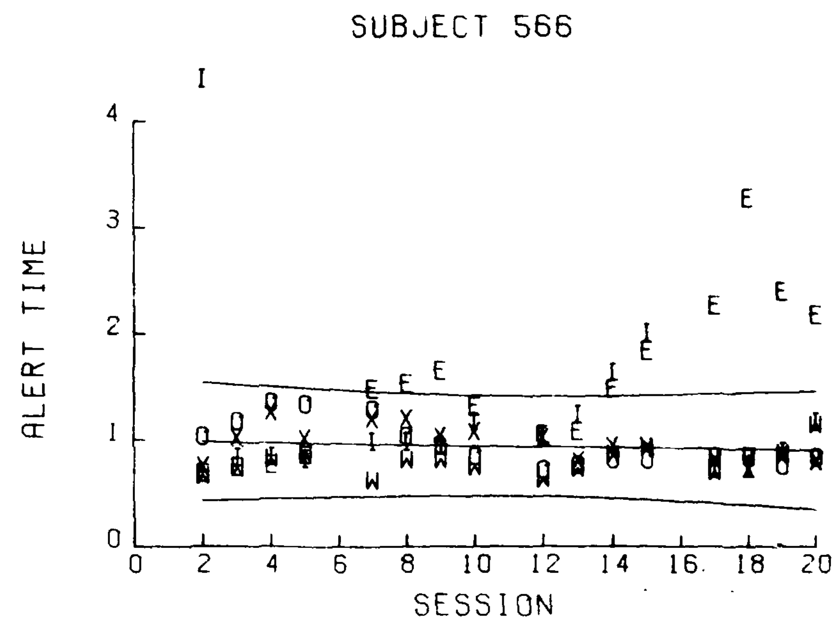


Figure A-6. Alert Light Reaction Time
Last Baseline Comparison





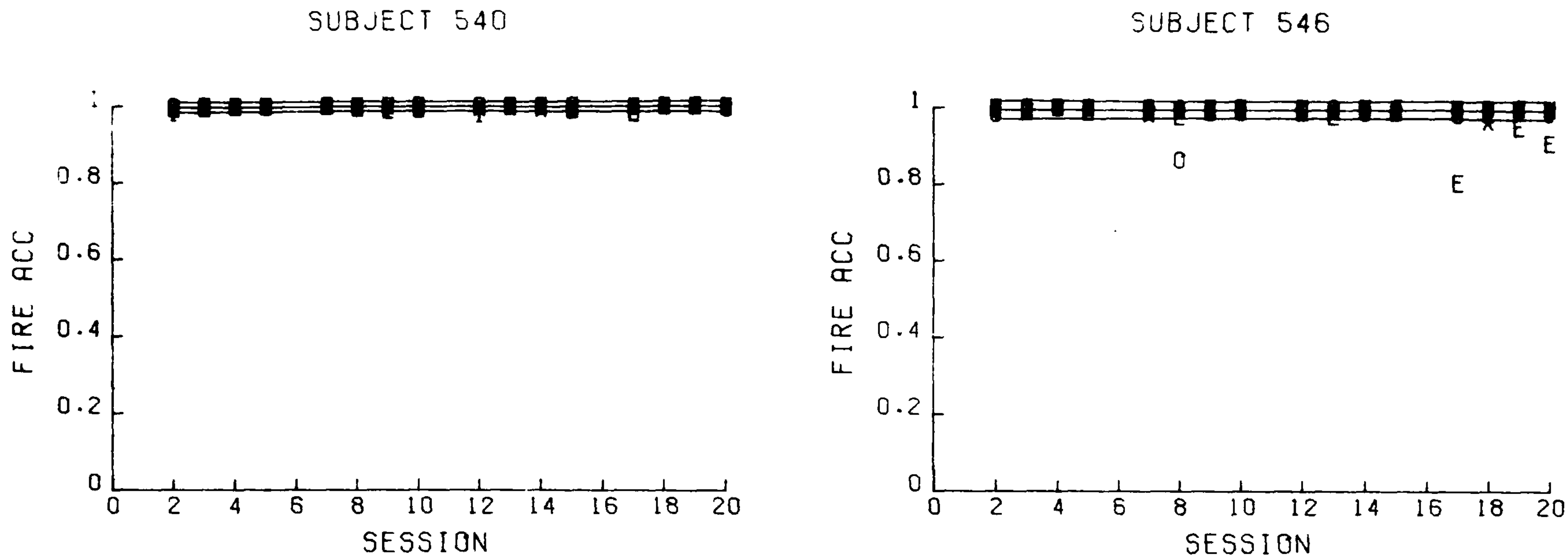
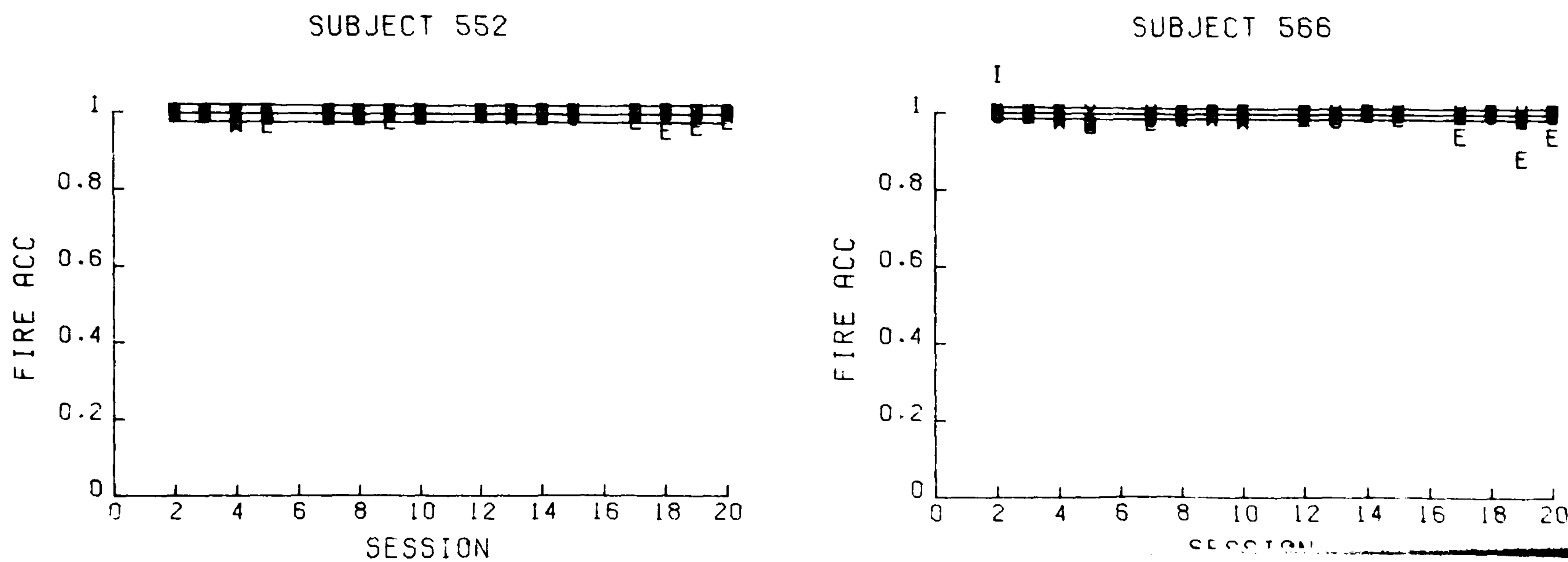
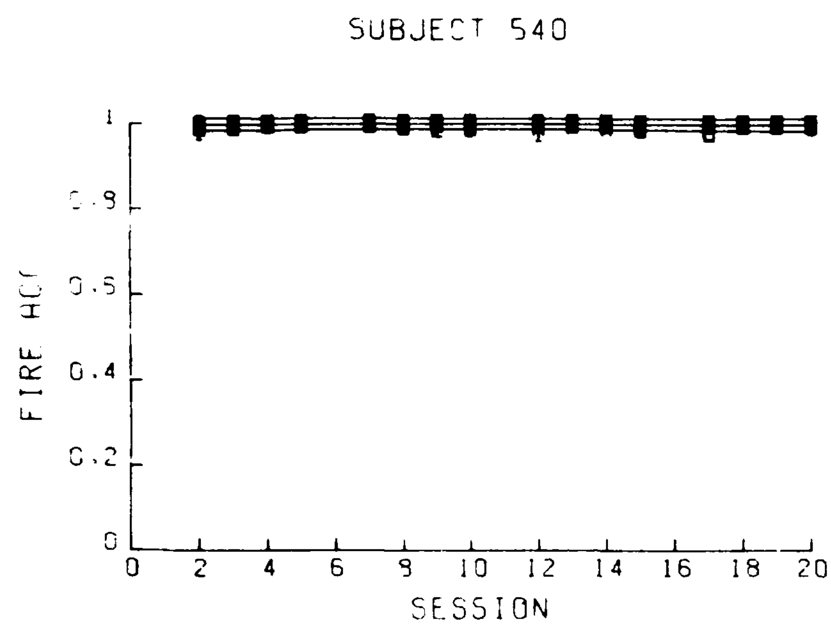


Figure A-7. Fire Light Accuracy
All Baselines Comparison





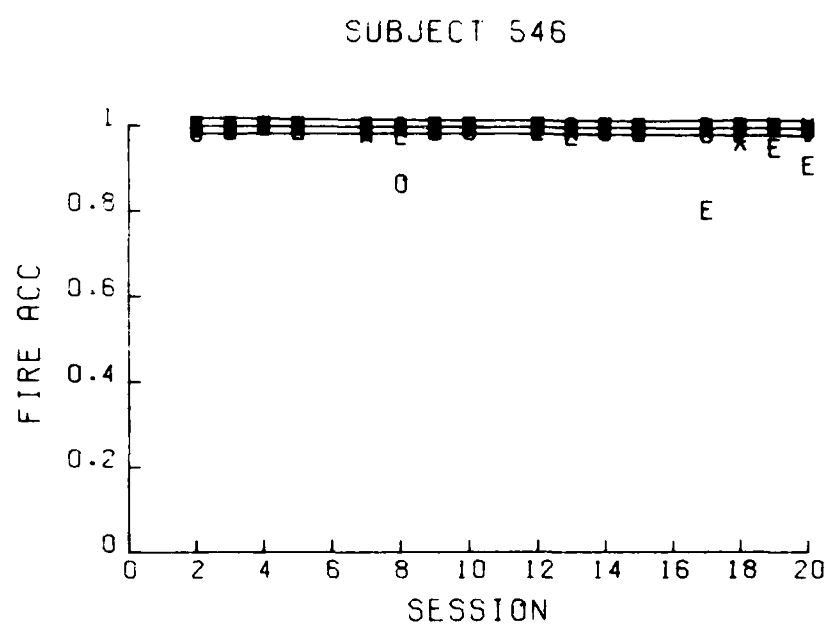
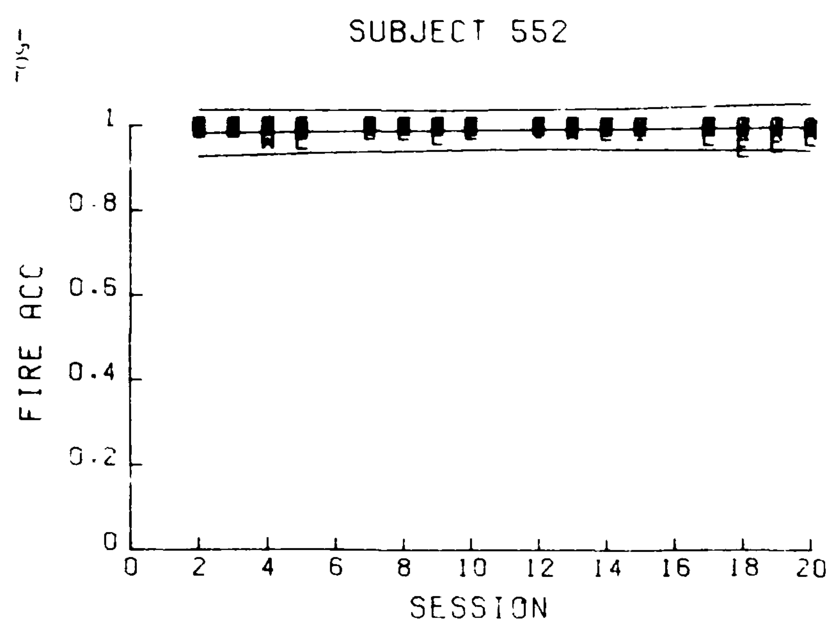
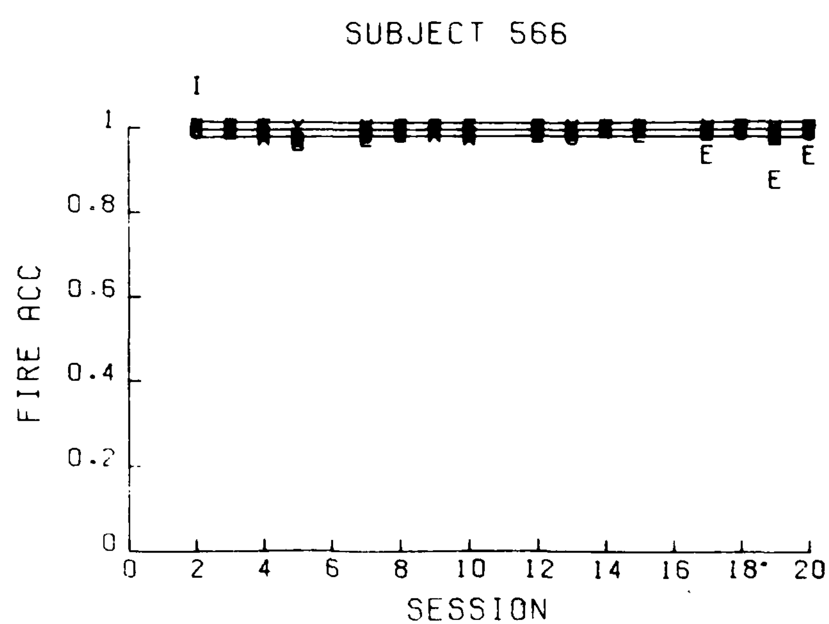
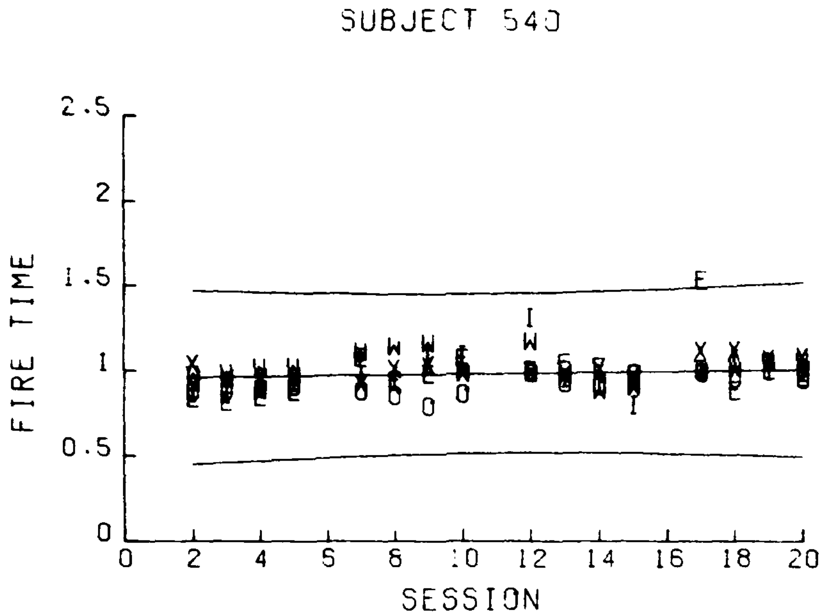


Figure A-8. Fire Light Accuracy
Last Baseline Comparison







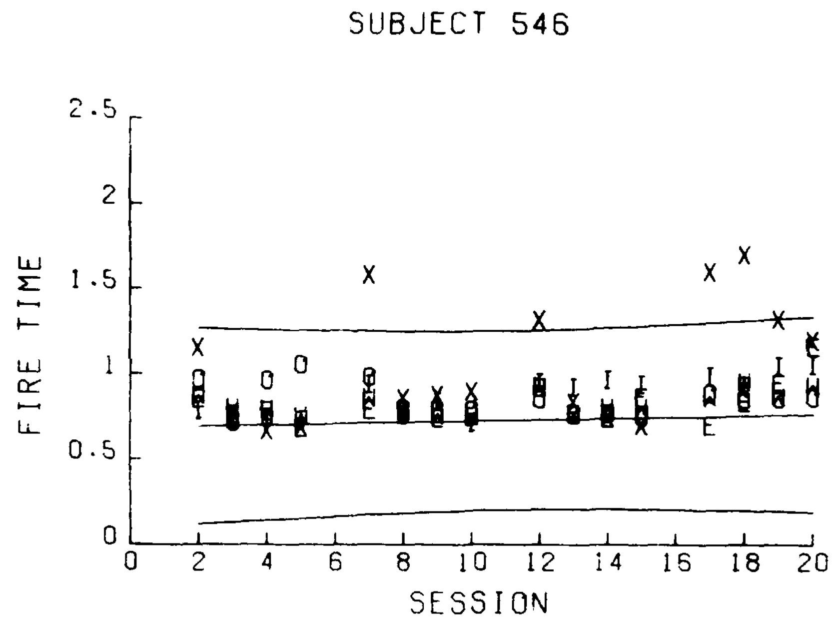
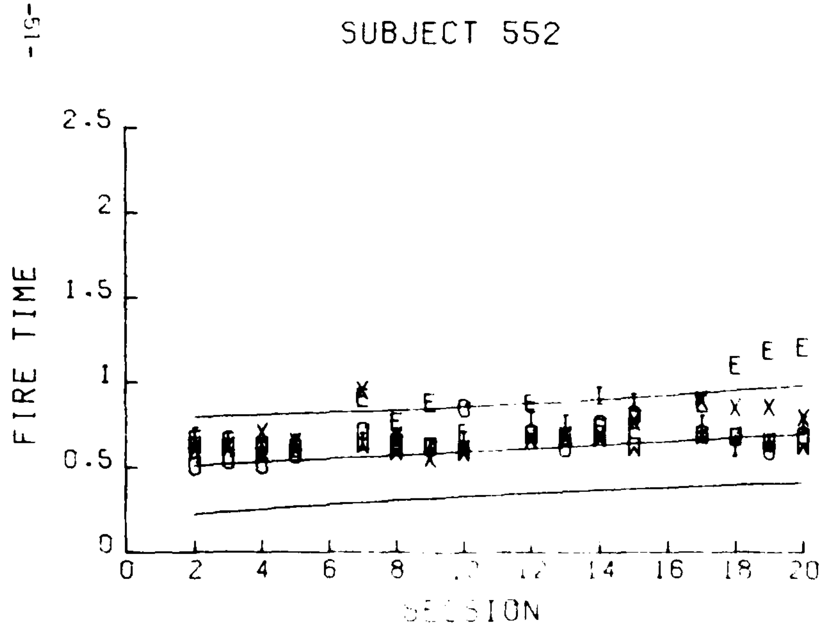
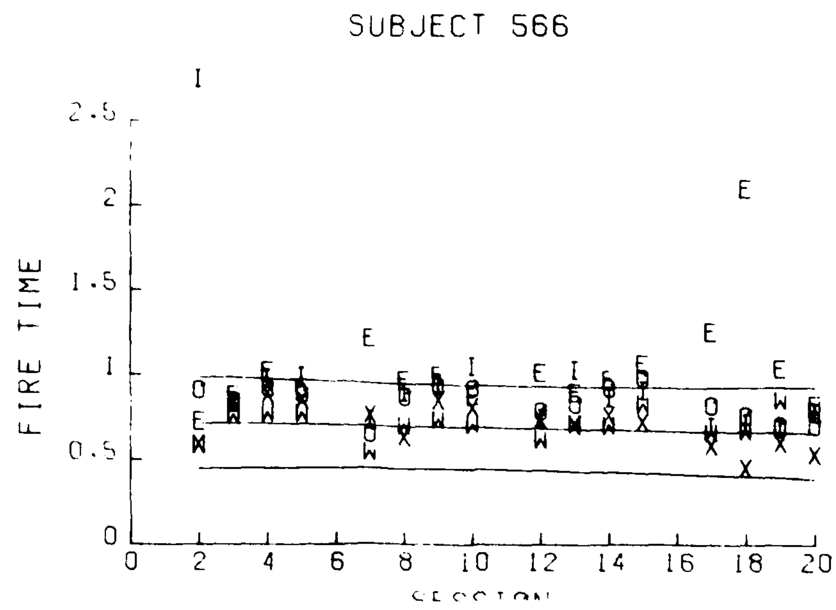


Figure A-9. Fire Light Reaction Time
All Baselines Comparison





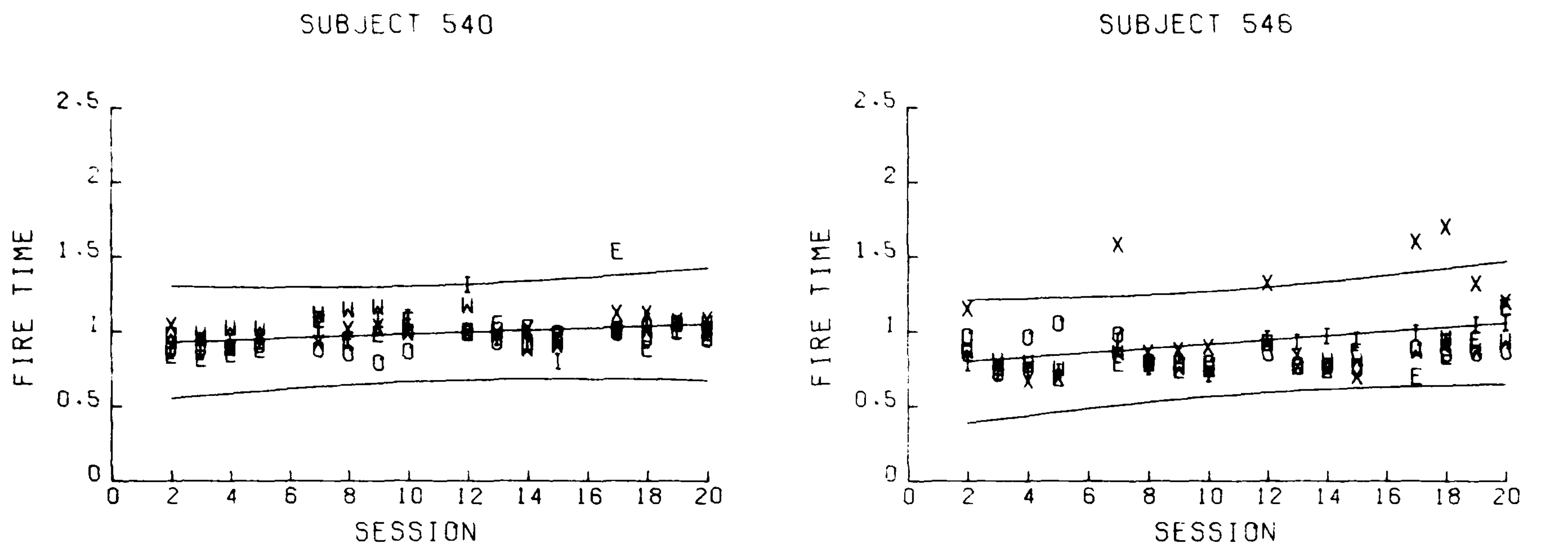
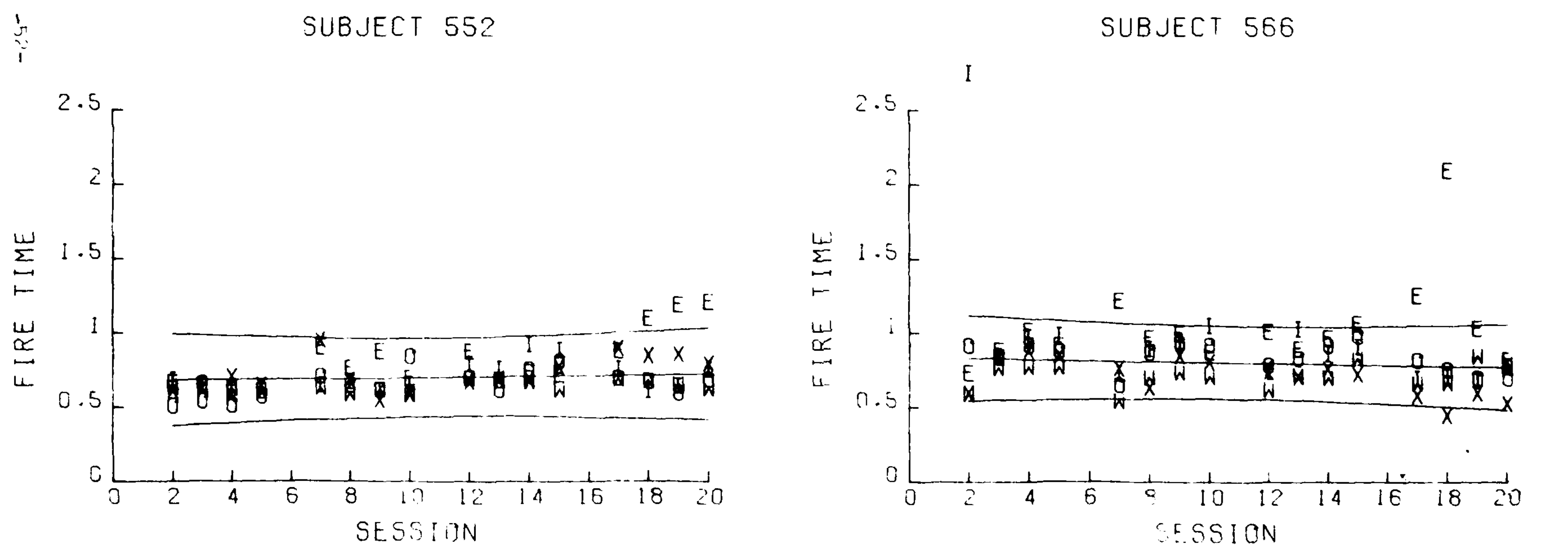


Figure A-10. Fire Light Reaction Time
Last Baseline Comparison



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